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B.S. Kurchman

PRECISION CASTING

Oborongiz

1954

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This book contains a description of the processes of precision casting which are described in their technological sequence. It also gives a description of the equipment and starting materials used, examples of the casting of heat-resistant alloys, with calculation of the charge and information on the organization of precision casting. The book devotes considerable space to the quality of castings, the description of the defects most frequently encountered, their causes, and the measures for controlling scrap.

The book is intended to raise the qualifications of workmen in precision casting departments and shops.

AUTHOR'S PREFACE

The directives of the Nineteenth Party Congress on the Fifth Five-Year Plan of Development of the USSR for 1951-1955 provides for a considerable increase in labor productivity by introduction of advanced manufacturing processes in all branches of the national economy. This demands mastery of advanced technology by the broad masses of industrial workers.

The book summarizes the work experience in a new progressive method of casting, namely precision casting, and is intended to increase the qualifications of workmen in precision casting departments and shops.

It is difficult for the author to write a text for increasing the qualifications and for training cadres in precision casting, since no proper plans and programs of instruction have been developed so far, and the literature dealing with this subject item in popular language is still inadequate. The author therefore recognizes that this book may have shortcomings. I would ask that criticisms of these shortcomings be sent to the publishers (Moscow I-51, Petrovka 24).

The author expresses his thanks to L.N.Gazez'yan, Candidate in technical sciences, for looking over certain Chapters of the manuscript, to Engineer A.N.Chernov for his editorial work, and to A.A.Lunev, Candidate in technical sciences and Engineer B.N.Meshchaninov for their valuable suggestions during review of the manuscript.

B.Kurchman

INTRODUCTION

The field of application of casting in modern production is constantly expanding. The shapes of the parts produced by casting have become more complex, new casting materials are being used, and assembly-line mass production is expanding. USSR scientists, engineers, and innovators of production are successfully effecting the mechanization of casting processes.

Nonferrous alloys in series production are more and more frequently cast in chill molds. The demands for higher precision of nonferrous alloy castings have led to the development of pressure casting in metal molds. The demands for higher mechanical strength of parts have led to the use of centrifugal casting methods. The need for precision steel casting, with very complex geometry, from steels and alloys difficult to machine has produced a new method of casting in industry, precision casting with patterns melted-out (or burned out).

The method of precision casting has long been a distinguishing badge of Russian foundrymen. The outstanding craftsmen in casting, V.Efimov and P.Klodt, used this method for producing remarkable masterpieces of the founder's art (the memorial to Minin and Pozharskiy at Moscow, cast by Efimov in 1818, and the sculptural group "Man Subduing Nature" at Leningrad, cast by P.Klodt in 1841-1850). They relied on the experience of many generations of Russian founders whose art goes back to antiquity. Many remarkable Russian foundry craftsmen, humble workers, whose names have not come down in history, have still bequeathed marvelous works of art to us as a heritage. The larger part of the artistic castings found by our

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archeologists in excavations were made by the method of wax-pattern casting. Jewelry is cast by this method even today. In industry, however, the method of precision casting with melted-out or burned-out patterns which are exceedingly difficult to work by any other method, has developed only after refractory alloys first began to be used.

The essence of the method of precision casting with melted-out patterns is as follows: The pattern of the part, made of a low-melting material (wax, paraffin, plastic) is coated with a facing layer, which is then dried. The pattern faced in this manner is then formed in sand. The mold is dried and the pattern is removed from it through the gating passages; then the mold is fired at a high temperature and molten metal is cast in it.

Thus the casting mold in precision casting is used only once. Precision casting differs from other forms of casting in that: a) the mold has no joints; b) a special highly refractory facing is used; c) the metal is poured into the hot mold. The absence of joints in the mold when casting parts of complex profile increases the precision of the castings, since even with the most careful assembly of jointed molds it is not always possible to avoid displacement and skewing. The use of a highly refractory facing layer makes it possible to obtain clean surfaces in parts cast of steels and alloys of high melting point and high casting temperature. The hot mold assures better filling with the molten metal.

The advantages of the method of precision casting include the following:

1) Possibility of casting parts of complex profile;

2) High accuracy and complete interchangeability of castings (the accuracy of this method of casting is as high as the third and fourth class);

3) Possibility of casting most metals, including refractory alloys (except for alkali metals, which react with the silica of the facing of the mold);

4) High finish of the casting surface, needing no additional machining; the finish corresponds to the 5-6th and in some cases even to the 7th class of

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finish;

5) Possibility of casting parts with minimum tolerances (the tolerance may be specified as 0.4-0.7 mm or, for parts of simple shape, as 0.2-0.4 mm).

Together with its favorable aspects, the method of precision casting also has serious shortcomings, which must be taken into account in selecting the production method. These include: need for extensive auxiliary material; increased use of electric power; excessive length of the cycle, which is as much as 5-7 days; inadequate mechanization of the process.

The advantages and disadvantages of precision casting determine the conditions for selecting this method of casting in the production of parts. The use of precision casting is recommended if the geometry of the casting is complicated; if the alloy used is difficult to work; if the alloy used is expensive, requiring reduced tolerances and minimum loss of metal in chips; large-series or mass production.

The method of precision casting in industry (aviation, automobile and tractor, instrument, etc.) is of very recent origin. There can be no doubt that the improvement of this method will still more expand the field of its application.

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I. BRIEF DESCRIPTION OF TECHNOLOGICAL PROCESS OF PRECISION CASTING

In contrast to the method of sand casting, where a large number of castings is made from a single wooden or metal pattern, in the process of precision casting each casting is made from an individual pattern. The need for patterns, whose number corresponds to the number of parts or articles to be produced, determines the first stage of the process.

Patternmaking in Precision Casting

In precision casing, patterns of easily fusible materials are used, and are removed from the mold during its drying and firing.

Paraffin wax, stearin, rosin, ceresin, beeswax, shellac, and compositions made of these substances, are used as materials for patternmaking. Cases of patternmaking from phenolic and carbinolic plastics are also known.

The patterns are cast in special dies. The dies for casting patterns are mostly made of metal (steel, aluminum, or bronze) and are suitable for making a considerable number of patterns. So-called semipermanent dies made of plaster, wood, cement, or fusible alloys, may be used for a number of patterns.

The geometry of the ultimate casting depends on the careful manufacture of the dies; therefore, dies for series production are always made in toolmaking or metal patternmaking or stamping departments with great accuracy and care. The design of the dies, the number of joints, and the closing mechanisms, determine to a considerable extent the number of castings that can be produced by the patterns, a fact that

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must not be forgotten in designing dies.

At present, there are several methods of casting patterns: free casting of the melted pattern composition into the die, pressure casting into the die on presses, and pressing the composition in paste form by special injection molding machines.

The pressure casting of patterns is the most productive method and is used in series production. The composition cast under pressure into the die assumes the form of the pattern, and after solidifying is cautiously extracted from the die. The patterns are checked for their basic geometric dimensions, after which they are assembled in blocks (sections) for subsequent group molding and casting. The assembly of the patterns is done either in jigs with simultaneous casting of the gating system, or by mounting (stick-weld) onto previously cast elements of the gating system, followed by soldering them together.

The assembled blocks (sections) are ready for molding, which is performed in two stages: a) covering the patterns with the facing layer (coating) and b) molding.

Facing and Molding of the Patterns

The preparation of the first layer of the mold, the facing, in precision casting, must be given special attention. The facing comes into direct contact with the molten metal; therefore, in casting refractory alloys, whose pouring temperature already reaches 1650-1670°C, this layer of the mold must be refractory to at least 1700°C, otherwise metal penetration will do considerable damage to the finish of the casting. The facing have sufficient strength; if the facing cracks when the mold is filled with metal, the geometry of the part is impaired, resulting in the formation of burrs on the surface and possibly to extensive leakage of metal from the mold.

The facing of the mold is applied to the pattern in the liquid form. The block of patterns is coated by repeated dipping in the facing compound, consisting of quartz dust (marshallite) and an organosilicon binder, ethyl silicate. The patterns are usually coated three to four times, the coating layers being dried each time in

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air and in ammonia vapor. The faced and dried blocks are now ready for molding.

The blocks of patterns are mounted on a flash board (cemented on with waste pattern composition, on which the molding flask (cast or welded of fireproof steel) is placed. The flask is either attached to the grooves of the flask board, or the flask joint and flask board are smeared with refractory clay; sometimes the joint between the flask and the flask board is packed with waste pattern composition. The molds so prepared are placed on a vibrator and filled with the molding compound.

At present, several molding compounds are in use. A liquid molding compound (up to 40% water) consisting of 80% of K50/100 quartz sand and 20% of alumina cement is the most widely used type for precision casting. Another molding compound is also in use: a so-called dry mix, consisting of 98-99% quartz sand (used), and 2-1% boric acid. In this case, the faces of the form are coated either with refractory clay or a special composition of sand and waterglass. Other molding mixes are used, containing fused quartz sand or grog as filler.

Recently a flaskless method of molding, using frames have been introduced.

The molding mix is packed into the flask and shaken on the vibrator for 3-10 min, after which the mold is allowed to dry naturally. In the case of wet molding, the natural drying is continued for 24-40 hrs (depending on the dimensions of the mold), while in the dry method the molds are ready for the next operation in a few hours.

Drying, Lining the Pattern, Firing the Molds, and Pouring the Metal

After natural drying, the molds are removed from the flask boards and are routed to the operation of drying and pouring out the patterns.

In many enterprises, the operation of drying on conveyor driers or thermostats is conducted simultaneously with the pouring of the pattern composition from the molds; the molds are gradually heated to 250-300°C (over a period of 16-20 hrs). During this time, the pattern composition melts and flows out, releasing the mold. Many plants do the drying and baking at the same time; in this case re-use of the

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pattern composition is entirely out of the question, since the composition will burn in the oven. Some plants melt out the composition with steam before drying. But this method is suitable only for pattern compositions of very low melting point (not over 80°C).

The molds after having been dried, are baked in electric furnaces at 300-900°C with a slow stepwise increase of temperature for 13-16 hrs; in this case, the residue of the pattern composition is burned, and the surface of the mold becomes smooth and hard.

The molten metal, as a rule, is poured into hot molds, which are delivered for casting immediately after baking. The filled molds are knocked out after solidification, and the castings are cut off from the runners, cleaned, and routed to the inspection department.

II. DIES FOR PATTERNMAKING

Designing the Dies

As noted above, the geometric dimensions of the casting produced depend almost entirely on the accuracy with which the dies are made. In addition, all the unpleasant peculiarities in the behavior of a given part during casting, due to its design (buckling, shrinkage, cavities, etc.), which cannot be eliminated by a rational modification of the casting technique, may be successfully eliminated during finishing of the dies. For this reason, the die-making must be considered the most important stage in mastering the process of precision casting.

In designing dies, the following must be taken into account:

1) Very careful finishing of the inner working cavity of the die and maintaining it in good condition during the subsequent work;

2) Simplicity of assembly and disassembly of the die and absence of parts in the working part of the die that are difficult of access for cleaning;

3) Reliable attachment of the die;

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4) Convenient removal of the pattern from the die, which is usually accomplished by the presence of the necessary casting cones and the absence of recesses;

5) Correct filling (or introduction) of the pattern composition into the die, so as to exclude the casting defects in the pattern (gas blow holes, failure to merge, shrinkage cavities, etc.);

6) Convenience in operation; if the die is not attached immovably to the press, its weight must be reduced as much as possible;

7) Long life of the die.

In designing a die it is necessary to take account of all the volume changes taking place in the pattern, mold, and casting, i.e., of shrinkage and expansion.

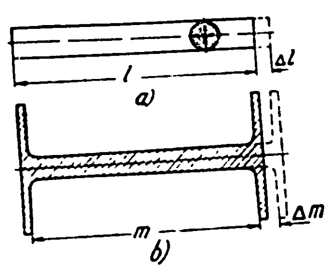

Fig.1 - Free Shrinkage (a) and Hindered Shrinkage (b) of a Casting

This question is exceedingly complex and at the present time cannot be considered completely solved for all parts, since the basic difficulty resides in their design. It is impossible, for instance, to extend the law of volume variation of a cylindrical rod of a length l and a diameter d (Fig.1) to a part of complex form: in percentage ratio, the amount of shrinkage of Δl of the straight rod will not at all correspond to the value of the shrinkage Δm, since in this case the shrinkage is not free but is hindered by the resistance of the composition of the mold, and to a great extent depends on the material of the casting, the mold, the duration of its packing on the vibrator, the degree of baking of the mold, etc.

However, certain conditions affecting the variations in volume through the entire production cycle must still be taken into account. In this case attention must be paid to the fact that, depending on the pattern composition selected and the technique of casting it into the die, the pattern is subject to a shrinkage of 0.5-2.0%, and the absolute value of the shrinkage of the pattern is inversely proportional to the pressure when casting into the die; the metal cast in the mold likewise has a definite linear and volume shrinkage; on the other hand, the mold material expands by as much as 1.5% during drying and baking. The shrinkage and expansion partially compensate each other, which must be taken into account in designing the die.

In casting a steel part, it will be reasonable to assume the compensated shrinkage (result of all shrinkages and expansions) to be 1.0-1.1%, but all parts of the die must be made with allowance for the necessity of subsequent finishing, i.e., must be made somewhat longer and thinner, so as to avoid adding new material during finishing in view of the fact that it is usually considerably more difficult to do this than to remove excess metal from the die.

Designers have more trouble in designing dies for parts with complicated contours, the so-called profiles, which are often encountered in casting guide buckets and working blades of turbines.

Let us assume that the profile of a turbine blade is to be cast, formed by the entering radius R (Fig.2) and the exit radius r, that the radius R_3 (with the center at the point O_3) represents the profile of the blade fare and that the profile of the trailing edge is formed by the combination of the two radii R_1 and R_2 (with the centers at the points O_1 and O_2) and the straight line T. In designing the die for this profile, the value of the chord a and the maximum thickness of the profile K must be determined analytically or graphically (from an enlarged profile); for the die, the chord a is lengthened by 1.0-1.2% and a new profile (the profile of the die) with enlarged chord a_1 and unchanged maximum thickness of profile K must be constructed. Then new radii R_1', R_2', and R_3' are selected, attempting to retain the profile of the blade face (i.e., $R'_3=R_3$). The somewhat elongated profile so obtained will not be thicker than the assigned profile (K remaining constant) which

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would be difficult to avoid in constructing an "outline" contour of the profile, allowing for shrinkage of all radii, a method which unfortunately many designers still use in designing similar profile dies. If we add to this the fact that the

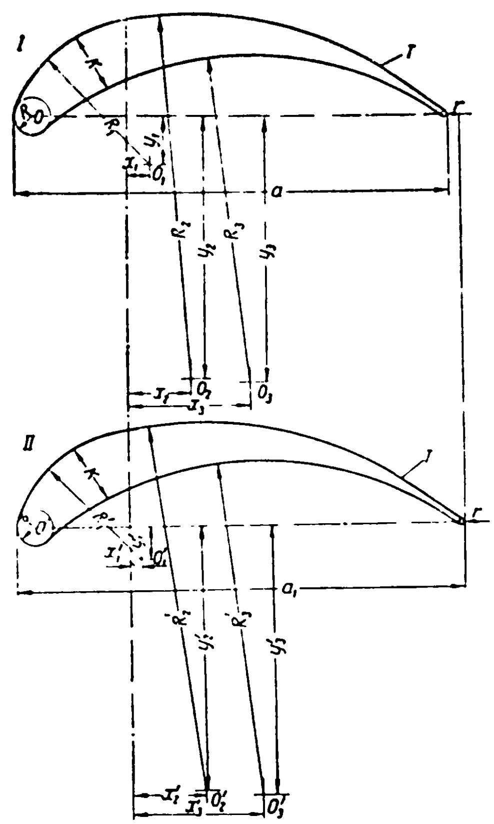

Fig.2 - Design of Die for Patterns of Turbine Blades

I - Profile of blade; II - Profile of die (before finishing)

maximum thickness of the profile K, along the depth of the part, is not constant in the casting (the thickness of the casting at the bottom is always somewhat greater

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than it is at the top), then it becomes obvious that finishing of the profile is unavoidable.

Die Making and Finishing

By production method and material, dies are subdivided into permanent and semi-permanent.

The latter include dies made of readily fusible alloys, wood, plaster, rubber, and cement. As a rule, they are made not from drawings but by casting in a master die, or, as some manuals put it, from a "master pattern": First, a master die of the part is made, allowing for subsequent changes in the dimensions of the pattern, mold, and casting, and then a die is made from this master die (Fig.3).

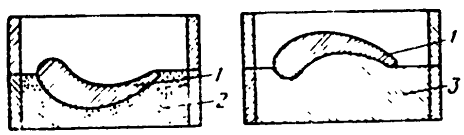

Fig.3 - Diagram of a Semipermanent Die from a Master Die (Molding and Pouring)
1 - Master die; 2 - Molding sand; 3 - Easily fusible alloy poured into first half of die.

Those dies are not strong, very inexact, and extremely short-lived. They are useless in series production and are suitable only for single castings, or for experimental work with a small number of castings, where the accuracy of the parts produced is not of substantial importance, but only their form matters.

For series production, steel dies with a hardened working part must be used. Aluminum dies wear out rapidly and require extreme care in work, so that they cannot be recommended for series work.

As a rule, a die is completely made up on metal-cutting machine tools, followed by gage finishing of the working surface, using fitter's tools.

The use of wedges, wing nuts and clamps as locks for dies is undesirable, since all these locking mechanisms require a large amount of time for servicing and are not reliable in operation. Bolts and nuts behave considerably better in operation, but their servicing also takes much time. The most rational mechanisms for locking dies obviously are eccentric clamps and pneumatic or hydraulic locking devices. If these mechanisms can be arranged on the casting press, together with the die, in a stationary manner, the problem can be considered solved.

Figure 4 is an exploded view of one of the simple steel dies. In this die, guide pins are unskillfully combined with locking bolts. Figure 5 shows a few types of dies for making patterns for vanes and blades.

A die, constructed from drawings, is put into operation and used for casting a small batch of patterns, followed by casting of the parts. Since the fluctuation

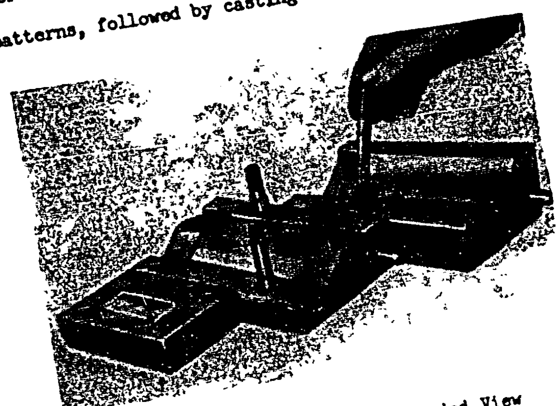

Fig.4 - Steel Die, Exploded View

in the dimensions of precision castings is 0.3-0.5 mm, confining the operation to a very small number of castings is not recommended and will lead to errors. Casting of two or three batches of 10-20 castings each is recommended. This will exclude random results. In many enterprises, the entirely unfounded custom has been adopted of considering a die to be completely finished after a single casting, when taken apart, has shown good coincidence of the coordinates along the theoretical profile after its measurement. This method does not exclude random deviations, possible in precision casting, and may lead to placing an insufficiently finished die in operation as well as to unnecessary repetition of the finishing. On finishing a die, it is necessary to measure, in a most careful way, along the principally important dimensions, all the castings of test batches, to tabulate the results of these test measurements and, after analysis, to decide whether to put the die into operation or to repeat the finishing. If enlarged profiles are used, the mean values of the measurements obtained must be plotted on the theoretical profile, which will give an objective picture of the state of the geometry of the casting and will allow avoiding errors that would be difficult to correct.

Serious attention must be paid to the surface finish of the inner working surface of the die, remembering that in precision casting all defects of a die, even insignificant ones, in the form of cracks or shrinkage cavities, are reflected in the casting. The finish of the working part of the die must correspond to the 8-9th class.

After casting a batch of castings of suitable geometry and finish, a certificate must be issued for the die, certifying to all the drawing dimensions that could be corrected during finishing. These data are entered in the die certificate, and the drawing of the die is modified in accordance with the corrected dimensions. Working sweeps and check counter-sweeps are then taken from the finished die, and the die is placed in series operation. The die certificate, together with the die is kept in the tool storeroom. The certificate shows the time of operation of the die, the date of verification at the equipment check station, and all corrections made on the die.

Operation of Dies

A die placed in operation must be assigned to one or several workmen and issued during the shifts. During operation, the inner working surface of the die must be carefully cleaned with wooden spatulas to prevent possible dents and scratches. At the end of operation, the die must be cleaned and greased (preserved) to avoid cor-

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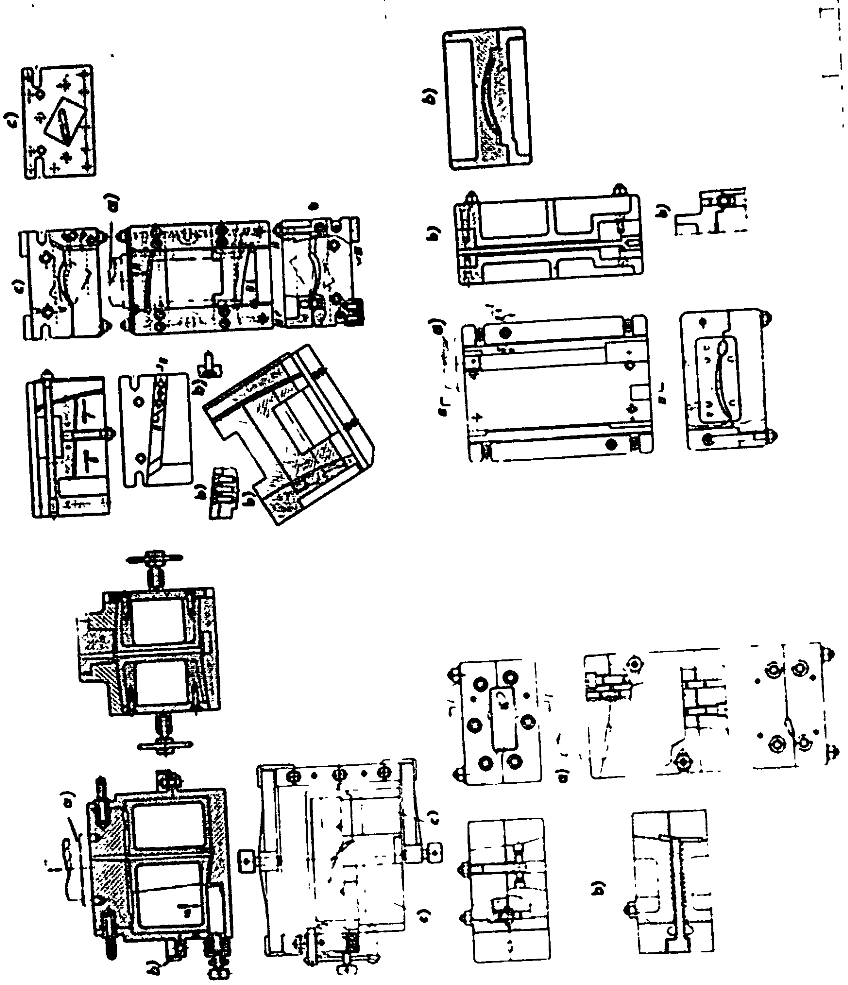

Fig.5 - A Few Types of Dies for Making Blade Patterns

a) Compression cylinder; b) Section through I-I, b) Section through II-II, b) Section through III-III; c) View along arrow A, c) View along arrow B, c) View along arrow C, c) View along arrow D.

rosion, which involves a long repair job on the die.

The die must be checked at the equipment check station at least once a month, and after casting every five thousand patterns. Normally, up to 200,000 patterns can be cast from each die, without major overhaul.

Periodically (at least once a month), check measurements must be made on the parts produced by casting from a given die. These periodic measurements on batches of 30-50 castings permits keeping track of the condition of the die and of its natural wear, which unavoidably leads to variations in its geometrical dimensions. If deviations of more than the established tolerance are found with respect to any dimension in the course of this check, the die must be removed from operation and the wrong dimension must be corrected. This checking is particularly necessary in series production, since a large number of castings (patterns) are produced from a single die, and a faulty dimension, if neglected, may be detected too late in the machine shop. With substantial filling-up of defects between operations and a cycle of 5-7 days, this leads to losses in semifinished articles (molds and patterns) and loss of time, interfering with the rythmic operation of the section and of the entire shop.

III. MAKING MELT-OUT PATTERNS

The Pattern Compositions in Use

A large number of recipes for melt-out pattern compositions are known. Many of them differ only little in their technological properties. In the absence of any printed manuals, each organization doing precision casting composed its own pattern mixture. The composition of this mixture largely depended on the materials available.

Table 1 gives the compositions of certain pattern compositions.

The raw materials for the pattern mixtures must meet certain requirements as to purity. They must not be contaminated with foreign substances, must be uniform, and

Table 1

Composition of Pattern Mixtures (in Weight Percent)

a)	b)	c)	d)	e)	f)	g)	h)	i)	j)	k)	l)
1	40	30	5	25	—	—	—	—	—	—	—
2	65	25	—	—	—	10	—	—	—	—	—
3	—	38	—	4	40	18	—	—	—	—	—
4	40	60	—	—	—	—	—	—	—	—	—
5	50	50	—	—	—	—	—	—	—	—	
6	75	25	—	—	—	—	—	—	—	—	—
7	85—90	—	—	—	—	15—10	—	—	—	—	—
8	32	65	—	—	—	—	—	—	—	3	—
9	—	—	—	20	53	—	—	—	—	—	27
10	70	20	10	—	—	—	—	—		—	—
11	—	—	—	—	—	15	80	—	—	5	
12	—	—	20	—	50	—	—	30	—		—
13	25	—	—	—		5	—	—	70	—	—

a) No.; b) Stearine; c) Paraffin; d) Ceresin; e) Beeswax; f) Rosin; g) Ethylcellulose; h) Halowax; i) Polystyrene; j) Abietic tar; k) Castor oil; l) Shellac

each batch must have the same properties as other batches. This requirement is usually met by carefully selected grades and a previously agreed state of the materials delivered. Cases are known where the same type of material, arriving at a plant at different times, differed sharply in technological properties, due to mixtures of different grades, resulting in increased spoilage.

All such materials must have minimum ash; the high ash content usually allowed in low-grade products considerably deteriorates the finish of the casting surface, and sometimes leads to spoilage. The materials for pattern mixtures must satisfy the requirements given in Table 2, which is a summary of the state standards for the physico-chemical properties most important for precision casting.

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Table 2

Specifications for Raw Materials Delivered for Pattern Compositions

№ a)	b)	c)	d)	e) f)	g)	h)	i)	j)
1	k)	u) 517	aa)	51—52	0,02		0,2	0,92—0,93
2	l)	784—42		50—52	0,01	ee)		0,91—0,97
3	m)	2488—47	80, 75; 67	80, 75, 67	0,03	0,1		0,91—0,94
4	n)	TU UZT —49	1—2	65—66	0,02			0,95—0,97
5	o)	797—41	bb)	65—68	0,05	0,05—0,1	0,3—0,4	1,0—1,1
6	p)	v) 1958—52		165	0,05			1,1—1,2
7	q)	w) 241—52	cc)	~200	0,02		0,1	—
8	r)	x) 1167-44	dd)	110—130	0,02		hh)	1,5—1,7
9	s)	y)		93	ff) 0,2		0,5	0,95
10	t)	z) 466		—16	0,008	ee)	0,25	0,95—0,97

* Oil Content not over 2 3%
** Use not recommended because of toxicity
*** Soluble in ethyl alcohol
**** Viscosity at least 17 3 Completely soluble in ethyl alcohol

a) No , b) Designation of material, c) GOST or OST, d) Grade, e) Physico-chemical properties, f) Melting point, °C, g) Ash, %, h) Content of mechanical admixtures, i) Moisture, %, j) Specific gravity, g/cm³, k) Stearine, l) Paraffin*, m) Ceresin, n) Beeswax, o) Rosin; p) Ethylcellulose, q) Polystyrene, r) Holowax**, s) Abietic tar***, t) Castor oil****, u) OST NKPP 517, v) TU MKhP 1958-52 [Specifications Ministry of Chemical Industry], w) VTU 241-52, x) TU NKKhP 1167-44, y) TU GUKh 01, z) OST NKPP 466, aa) 1-2 distilled, bb) Highest, 1; cc) Block, marks D and T, uncolored, dd) Class A, ee) Absent, ff) Not over 0 2, gg) Absent, hh) Not permissible

Low-melting compositions which contain paraffin wax, stearine, ceresin, wax, and rosin, are usually boiled in electric water baths or thermostats (Fig.6). The raw materials are ground into lumps 30-100 mm in diameter and placed in the bath. For low-melting materials, the order of charging is not of substantial importance. Usually the principal component is put in first and the others are added as it melts.

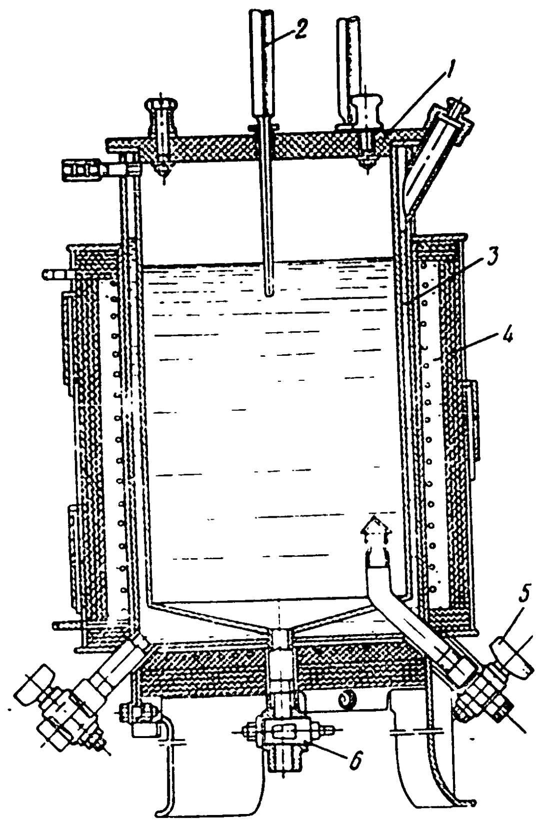

Fig.6 - Electric Bath for Boiling Pattern Composition

1 - Removable cover; 2 - Thermometer; 3 - Water jacket; 4 - Thermocouple; 5 - Cock for draining pattern composition; 6 - Cock for draining sediment

During the melting, the mass is repeatedly stirred. After complete melting, the mass must be kept at a temperature of 80-90°C for 30-40 minutes, after which it is tapped into special vessels, which are generally made of stainless steel. For particularly vital thin castings, the composition can be strained through a No.100-140 brass sieve during the process of tapping.

The pattern compositions containing stearine, paraffin wax, ceresin, wax, rosin, and shellac, have a very low boiling point and pouring poing, about 50-80°C. Pattern compositions containing holowax, ethyl cellulose, and polystyrene, melt at a considerably higher temperature, 110-250°C.

The use of low-melting pattern compositions requires very careful organization of pattern making since, at the slightest inaccuracy in handling the patterns made of these compositions, they become deformed and lose the necessary precision. It is desirable that the room for patternmaking from mixtures with a low melting point be provided with an air-conditioning system keeping the room temperature within 15-25°C, which is not always possible under the conditions of series production. However, the use of low-melting mixtures has also certain advantages, particularly convenience in melting the patterns out of the molds by steam or hot air, and possibility of re-using the mixture melted out of the molds, which, after regeneration, may be used up to 50% in a new pattern mixture. Nevertheless, for series production, higher melting compositions with a melting point not lower than 110-125°C should be selected.

Compositions with ethyl cellulose added, whose melting point is 110-125°C, are made in larger electric oil baths. Ethyl cellulose is scattered into the completely melted mixture and is left to dissolve over a longer period of time (0.5-2 hrs) after which a sample is taken; a small amount of the melted mixture is poured on a smooth metal plate. Isolated white granules of undissolved ethyl cellulose are permitted. The finished composition is poured into molds.

The KPTs pattern mixture (rosin, 50%; polystyrene, 30%, and ceresin, 20%) has proved valuable in series production.

Patterns prepared from KPTs mixture have the highest mechanical strength and are less subject to flexural deformation, since the granules (a favorable factor raising the precision of casting), well fill the mold and ensure a satisfactory surface finish. The disadvantages of the KPTs mixture are fire hazard (the mixture burns, because of the high polystyrene content) and the difficulty of melting it out of the mold. As a rule, this composition is removed from the mold by burning.

KPTs composition is prepared as follows:

An electric bath (Fig.7) is charged with rosin, pre-ground to 30-50 mm lump size; as the rosin is melting, the ceresin is added at a temperature of 140-160°C. The melted rosin and ceresin are tapped into a vessel of stainless steel prepared in advance, through a No.100-140 brass strainer. The strained composition is again poured into the bath, and the polystyrene is added to it in portions. The bath temperature is raised to 220°C. The mixture must be stirred frequently and thoroughly. After melting, the mixture is kept in the bath at 200°C until no more air bubbles form and then is poured into a mold.

To avoid ignition of the mixture, which would take place at 350°C, the electric bath must be equipped with a thermostat.

All pattern compositions must be boiled under hoods provided with forced draft ventilation. The mixture, after cooling in the mold, is broken up into bars, and in this form is ready for the second melting and casting of the patterns.

Technique of Patternmaking

The technique of patternmaking is determined to a considerable extent by the pattern composition used. The low-melting compositions for non vital simple castings may be teemed freely into the dies which, in this case, must have a branched runner part to compensate for the relatively great shrinkage. To accelerate the cooling of the patterns and to speed up the turnover of the dies with low-melting compositions, the method of filling the dies with the composition in paste form is

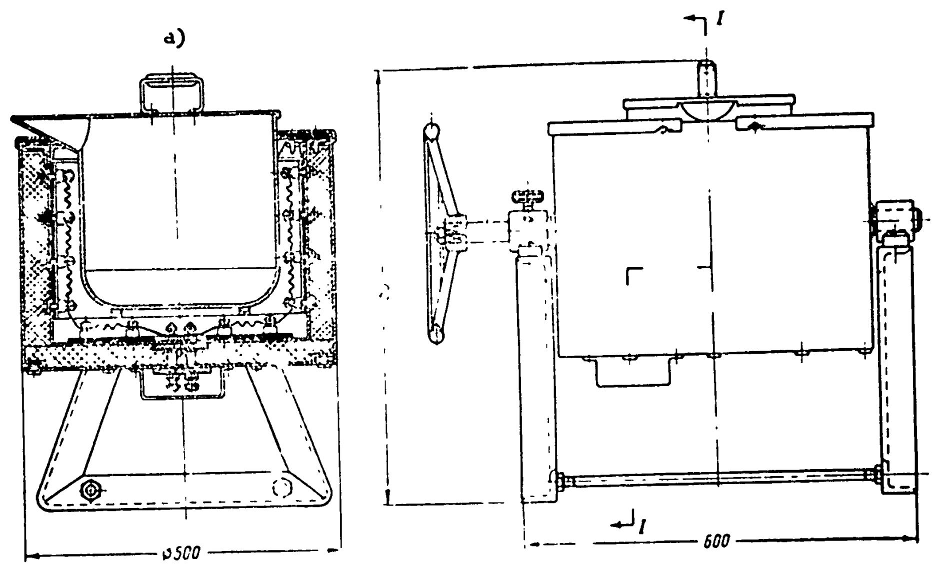

Fig.7 - Electric Bath for Boiling KPTs Mixture

a) Section through I-I

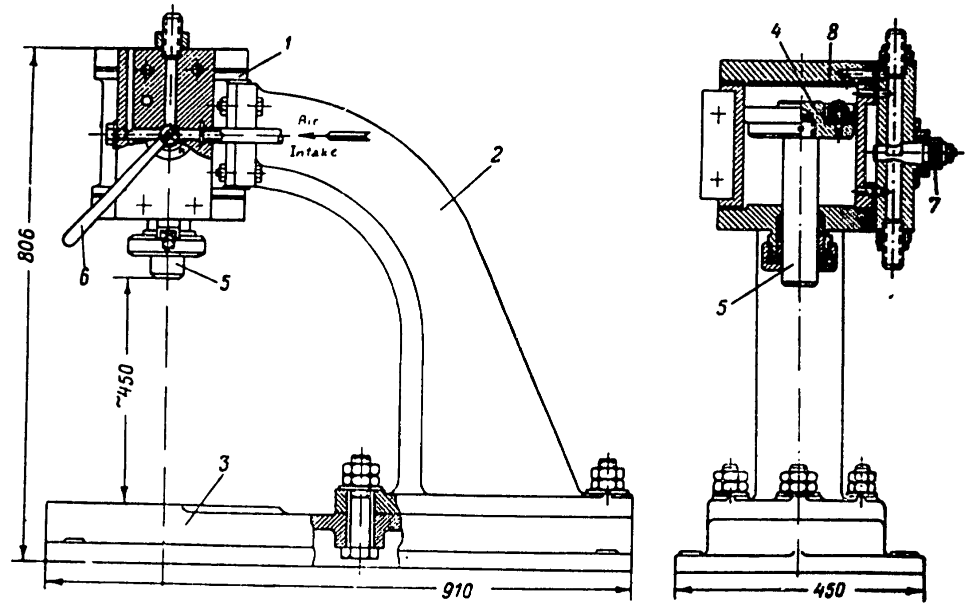

Fig.8 - Pneumatic Press for Patternmaking

1 - Press Cylinder; 2 - Bracket; 3 - Platen; 4 - Piston;

5 - Rod; 6 - Handle; 7 - Cock; 8 - Gasket

sometimes used. The solidified pattern mixture is carefully scraped out and, in the form of paste, is introduced into the die under pressure by a special funnel box.

In view of the long time taken by the process of patternmaking, and of the inadequate mechanical strength and relatively great shrinkage of the patterns, neither the method of free pouring nor that of filling the dies with the mixture in paste form are satisfactory for series production.

The method of patternmaking by filling the dies under pressure has proved most satisfactory.

The pattern composition, prepared in advance, is placed in a thermostat, where it is kept throughout at constant temperature. The temperature of the mixture in the thermostat is kept at 70-80°C for lower-melting compositions, 120-130°C for compositions with ethyl cellulose, and 165-180°C for KPTs compositions. Up to now, no satisfactory automatic metering injector has been developed, and the mixture is usually poured into the receiver of the press by means of a special measuring ladle.

The inner crucible of the thermostat and the ladle should be made of stainless steel. It is recommended that the ladle be greased before use, with a 50% solution of castor oil in alcohol, or with transformer oil, which makes it easier to clean after each use.

At present, the various plants use widely varying types of presses for casting the patterns. Occasionally, hand-lever presses are still used, which are suitable for casting small uncomplicated patterns.

Pneumatic presses, operating from a compressed-air line under a pressure of 3-5 atm (Fig.8) are widely used in some plants. The design of this press is simple and it is convenient to operate. The disadvantages include the imperfection of the filling mechanism and the nonstationary attachment of the die, which requires manual assembly and disassembly of the die. The press develops a force up to 700 kg.

At many plants, hydraulic presses are used (Fig.9). Some of these are provided with a thermostat for the pattern composition. The press uses oil as the working liquid. The pressure in the press system is 1.5-3 atm.

The process of patternmaking on a pneumatic press consists of the following operations:

1. The cavities of the disassembled die are carefully wiped with clean rags.

2. The working cavities of the die are oiled with transformer oil, using a tampon or a soft rag (lubrication with castor oil and alcohol is considerably more expensive and should not be used in the production process).

3. The die is assembled in strict sequence, applicable for the given type of die; no modification in the order of die assembly is permitted, since this may lead to incorrect assembly or breaking of the dies.

4. Place the die on the platen, aligning it with the mark (to avoid misalignment).

5. Close the feeders of the die with a sheet of parchment (a paper seal, preventing partial filling of the die before pressing).

6. Using a tampon, oil the filling device (cylinder and plunger) with transformer oil and align it on the die by the mark on the cylinder, in such a way that the edges are tightly pressed against the die (the paper seal will thus be between the die and the cylinder; ensure close contact, the cylinder face and the upper die cover are ground).

7. Oil the inner surface of the pouring ladle with transformer oil, and, removing a portion of the pattern mix from the thermostat with the ladle, pour it into the cylinder of the pouring device.

8. Place the plunger in the cylinder and close the press jacket.

9. Start up the press.

10. After teeming the compound into the mold and stopping the plunger of the press in the lowest position, keep the die under pressure, using an hour glass, for exactly 1-5 min (the time of pressing depends on the size and shape of the articles).

11. Switch the press reverse (in the upper position, the press turns off auto-

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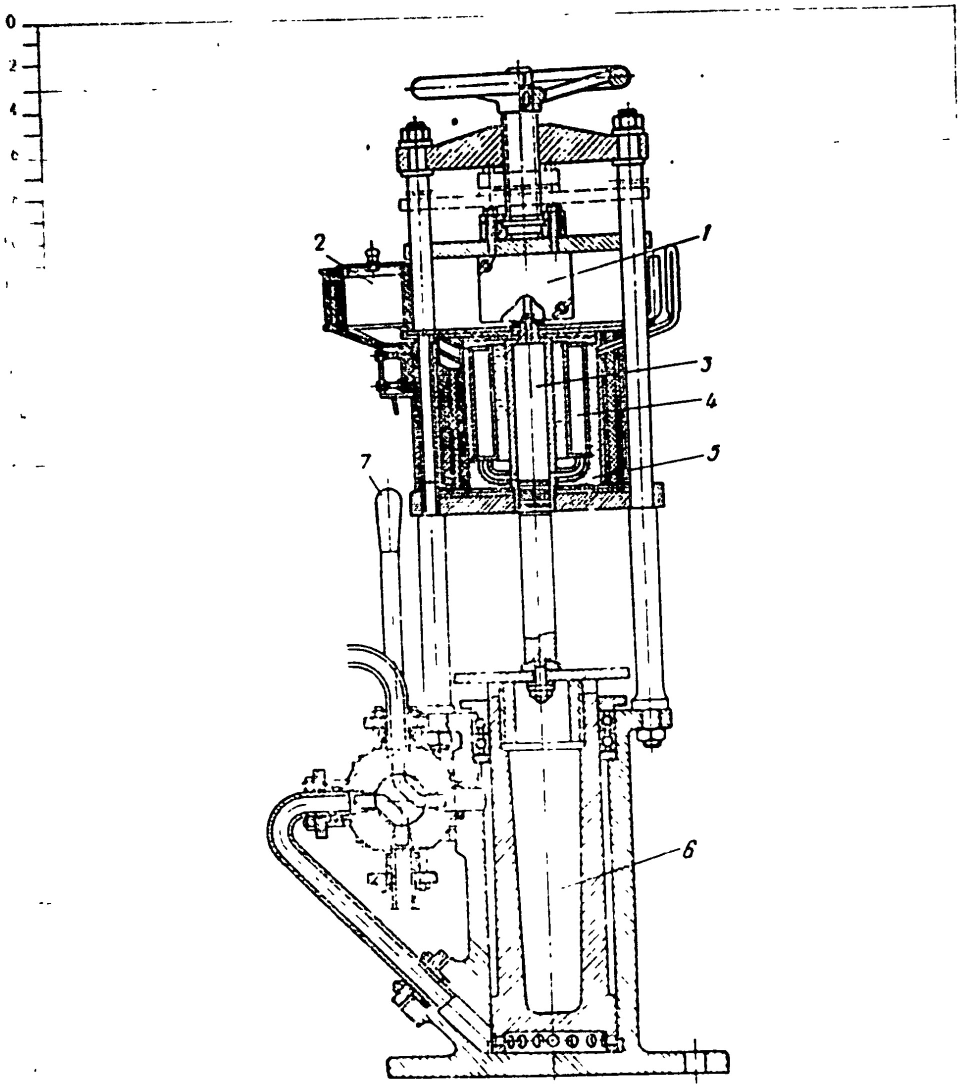

Fig.9 - Diagram of Hydraulic Press

1 - Die; 2 - Hopper or tun dish for charging pattern mix; 3 - Working cylinder; 4 - Intermediate cylinder; 5 - Water jacket; 6 - Hydraulic cylinder; 7 - Handle

matically).

12. Open the protective enclosure of the press, remove the die to the place for assembly and disassembly, remove the pouring device or runner, and disconnect it by means of the soft-alloy knockout rod.

Disassemble the die in the reverse order of assembly and, carefully removing the pattern from one of the parts of the die, place the finished pattern on the rack (Fig.10).

The residues of the pressed composition and the spoiled patterns may be returned to the thermostat.

In view of the relatively long machine time (1-5 min) it is advisable to operate with one press, using two dies of the same type. At the instant of disassembles and assembles a second set and prepares it for filling. After disconnecting the press in the upper position, the operator takes the first set off the platen and, replacing it by the second set, again exerts pressure. This method of working, which was first used by patternmaker P.V.Kudishina, allowed an increase of over 70% in labor productivity in patternmaking.

After pressing, a fin usually remains on the patterns along the joints of the die. The pressman, when molding a pattern should not be forced to remove this fin, since this would increase his work load and reduce the productivity of the press. The pattern, after removal, should be inspected, and checked for surface finish, absence of cracks, air bubbles, and cracked joints; but it is advisable to combine the cleaning of the patterns with the subsequent operation, that of assembling the patterns into blocks.

IV. CLEANING THE PATTERNS AND ASSEMBLY OF BLOCKS

Specifications for the Finished Pattern

The specifications to be met by the finished pattern are as follows: The pattern must accurately reproduce the contours assigned by the die. The geometric

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dimensions of the pattern must be within the range of tolerances (for instance, for a pattern of 150 mm length and 10 mm cross-sectional thickness, the permissible deviation is ± 0.2 mm); the buckling of the pattern must be strictly limited. No through cracks, gaps and open joints, air bubbles, or groups of foreign inclusions are allowed on the surface of the pattern; the maximum number of foreign inclusions, not more than 0.5 mm in diameter, must not exceed eight for the entire pattern; likewise, a small stratification of the pattern (markings) due to the teeming temperature of the composition, is permissible. Individual defects on the machined surfaces of the article can by corrected by filling them in with pattern compound.

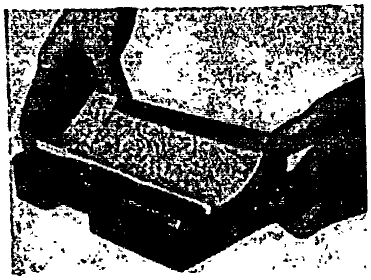

Fig.10 - Removal of the Pattern from the Die

Cleaning the Patterns

The cast patterns then go to the cleaning. The fin along the edge of the pattern is removed with a special slicker (Fig.11). In cleaning, particular attention must be paid to integrity of the pattern edges and to maintenance of the assigned radii along the edges. All defects to be corrected (individual casting grooves, fins) are filled in with melted pattern mixture by means of a slicker and an electric soldering iron.

The working place for the assembly and cleaning of patterns is provided with the following devices and tools: a) a control board for checking the patterns for buckling; b) an electric bath filled with melted pattern mix and operated over a step-down transformer at a voltage of 12-18 volts; c) an electric slicker and an electric soldering iron for filling in defects; d) a special knife for cleaning the patterns. In addition, various measuring tools are necessary: calipers for checking the length,

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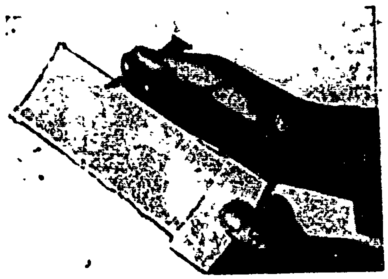

Fig.11 - Cleaning the Pattern with a Slicker

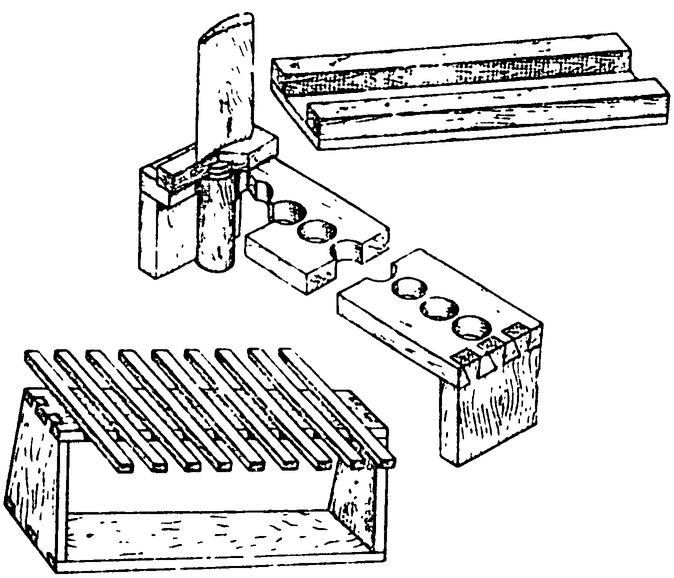

Fig.12 - Types of Racks for Storage of Patterns

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flat and round braces; scale and French rulers; profile templates; instruments for measuring torsion.

In cleaning patterns, deformation of the working part of the pattern must be avoided. Since the pattern material deforms easily, it is forbidden to stack the patterns. The patterns, both before and after cleaning, must be placed with extreme care in a position that permits no buckling; it is preferable to place the patterns in special niches or on portable racks (Fig.12).

Assembly of Patterns into Blocks (Sections) for Group Pouring

In casting relatively small parts (up to 400 gm) it was found that group casting is considerably more advantageous than individual casting. This is explained by the smaller relative consumption of metal in group casting, by the smaller number of molds to be poured, by the smaller amount of dross in the poured metal. In addition, group casting permits a more efficient utilization of the soles of the drying and baking ovens. For this reason, only group casting of parts is generally used in large-scale precision casting.

A few parts of the same type, interconnected by a common gating system, is known in precision casting as a "block of castings",or, simply, a block or section.

In assembling patterns into a block, a gate arrangement is best suited for the production of flawless parts must be selected.

Gating Systems. The gating system in precision casting must meet the following requirements:

1) reliable production of parts without casting defects such as ridges, split seams, local overheating, brittleness, blowholes, undercuts, dirt, slag inclusions, or buckling;

2) minimum weight and, consequently, minimum relative metal consumption per casting;

3) minimum over-all size of the block, thus resulting in reduction in mold dimensions, weight of the molding materials, and specific consumption of the sole

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area of the baking oven per casting;

4) convenient assembly of pattern into a block, applying mechanized assembly methods;

5) convenience in removal of castings and in primary sandblasting in the blocks.

Besides these basic requirements, convenience in setting up the mounted and coated block must also be taken into account in selecting the gating systems, since the blocks will have to stand a certain length of time while being patched; the necessary slope for complete removal of the pattern mix from the mold during the tapping process is a prime factor.

It is very difficult to meet all these requirements; therefore, the selection of a gating system is usually preceded by extensive experimental work.

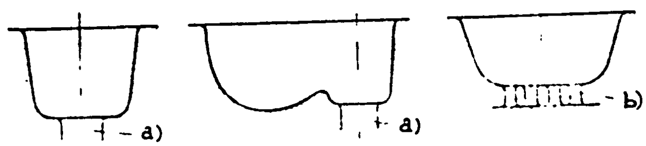

Fig.13 - Pouring Basins

a) Downsprue; b) Filter holes

In precision casting, as in any other casting process, the same elements and groups of elements of the gating systems are used. These include the following:

Pouring basins or metal runners (Fig.13) into which the metal is teemed from the ladle. Besides the usual requirements for this part of the gating system (slag retention, control of the casting rate), a pouring basin in precision casting must be strong, must not yield dross, and, on its upper face must have a sufficiently large area to support a block placed on it after assembly and coating. For this, in arranging the pouring basin at the center of the casting, its face area must be not less than 1/8 of the area occupied by the circle describing the casting; if the dish is not located at the center of the casting, its frontal area must be increased, or the casting must be provided with additional supports (the running channels for tapping the pattern mix from the deep risers and sprues are used for this purpose).

Most of the downsprues (Fig.14) in precision casting have a round cross section and are straight (the diameter of a downsprue, as a rule, must be equal to 0.25-0.33 of the lower diameter of the pouring basin); occasionally, in the case of particularly vital thin-walled and ribbed castings, the use of a wedge inlet is recommended. The essential difference between them is that the round downsprue does not prevent a rapid discharge of the metal which entrains a large amount of dross into the casting, while the wedge inlet acts as a retarder and reduces the rate of flow of the casting, thus retaining the dross. In precision casting, zigzag downsprues are not in wide use, since they favor the formation of cracks in the paint and transfer of part of the facing layer of the mold into the metal.

The runners (Fig.15) conduct the metal to the castings and to the feeding head of a casting. Most of the runners are of round or trapezoidal cross section; runners of semicircular section are used less frequently. The cross-sectional area of

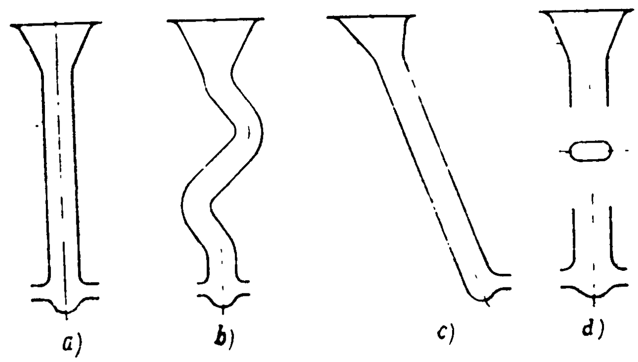

Fig.14 - Types of Downsprues

a - Straight circular section; b - Zigzag; c - Inclined; d - Straight, flat section

a runner is usually 10-15% smaller than the cross-sectional area of the downsprue.

The runners are connected to the ingates of the casting, which are of round, flat, or wedgelike cross section (slotted inlets). For particularly important castings, slag traps are provided in the runners (Fig.16).

At the points of excessive casting stresses, additional risers are installed to guarantee complete feeding of such places, even when the metal crystallizes (Fig.17). The mass of the metal in the risers must be considerably larger than the mass of the place being fed (not less than 6-8 times). In installing a riser it must be so selected that the metal in the riser is the last to solidify, otherwise the riser might "work for itself" by aspirating metal from the casting, which would lead to spoilage. In precision casting, the installation of so-called closed (deep) risers, should be avoided as far as possible, since these very much complicate the form, and preference should be given to open risers.

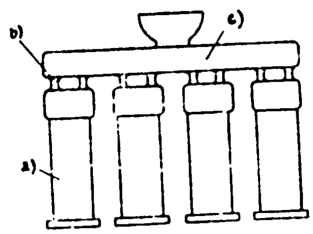

Fig.15 - Diagram of Block for Group Casting, with Runner

a) Detail; b) Ingates; c) Manifold Header

In a large number of precision casting works, a greatly expanded pouring basin is used as a riser, after the pouring, a heat-insulating powder is sprinkled on the dish to protect it from rapid crystallization. However, other gate ends, including deep ones, can be used; if necessary for the quality of the casting, such ends must be used; the same is true of the risers, whose purpose is to promote the removal of gases from the mold. A riser is often used as a gate for additional feed for the casting (Fig.18).

<u>Assembly of Blocks</u>. At present, two methods are used for assembling patterns into a block; the assembly of blocks by soldering to previously cast elements of the gating system, and the method of jig assembly.

Assembly by soldering has the advantage that it requires no devices other than universal ones. The elements of the gating system are cast (pouring basin, downsprue, runners, etc.) are cast in special dies, usually by free pouring. Checking with the assembled sample block, the assembler solders the individual elements together and

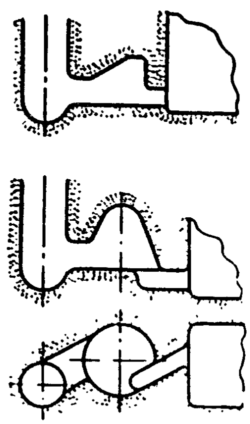

Fig.16 - Skimmers

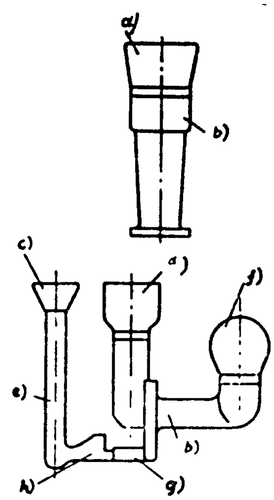

Fig. 17 - Risers

a) Gate-Riser; b) Part; c) Pouring Basin
d) Downsprue; e) Riser; f) Closed gate;
g) Ingate; h) Skimmer

then solders the patterns to them. He verifies the necessary dimensions, using a scale gage. The principal tools used by the assembler are the electric soldering iron, slicker, and knife. By accurately heating the soldering spot and by forming a seam on the melted pattern composition, reinforcement of the individual parts of the block is obtained. Assembly by soldering requires a highly qualified assembler and has the following disadvantages: excessive time for the assembly, low strength of the attached elements, and nonstandard character of the block which is unavoidable in hand work. Because of these great disadvantages, the method of manual assembly of blocks by soldering, which is used mostly with low-melting pat-

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tern mixes, is gradually being replaced by a more advanced method, that of jig assembly.

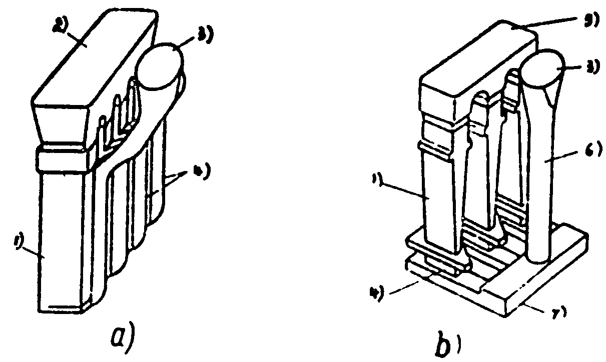

Fig.18 - Diagram of Block for Group Casting

a - Casting from top; b - Siphon casting

1) Part 2) Gate; 3) Dish; 4) Slit ingates; 5) Gate-Riser; 6) Downsprue; 7) Runner

The essence of jig assembly is that the patterns to be assembled are placed in a special jig and are attached by free pouring of the pattern mixture into the jig whose cavity is one of the elements of the gating system, or is itself a completely developed gating system. With jig assembly, every effort must be made for maximum simplification of the gating system, which in turn leads to simplification of the jigs. It is desirable to make the entire gating system as a single jig; resultant complexity of the jig is justified by the speed-up in constructing the blocks.

If it is impossible to make the gating system in a single jig, consecutive assembly of individual elements into jigs is recommended, followed by final assembly of the block, which, again, is preferably done in a conductor. If the design of the block does not allow the use of a jig for final assembly of the block, this operation must be performed by soldering; in this case, to ensure complete uniformity of the blocks and to make measurements during the work unnecessary, special yards, which

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greatly accelerate the work, must be used.

The jigs for assembly of patterns, like the dies, are made of metal. Since the mixture is charged into the jig, as a rule, by means of free pouring, it follows that jigs can be made of steel as well as of light alloys (aluminum, magnesium, etc.).

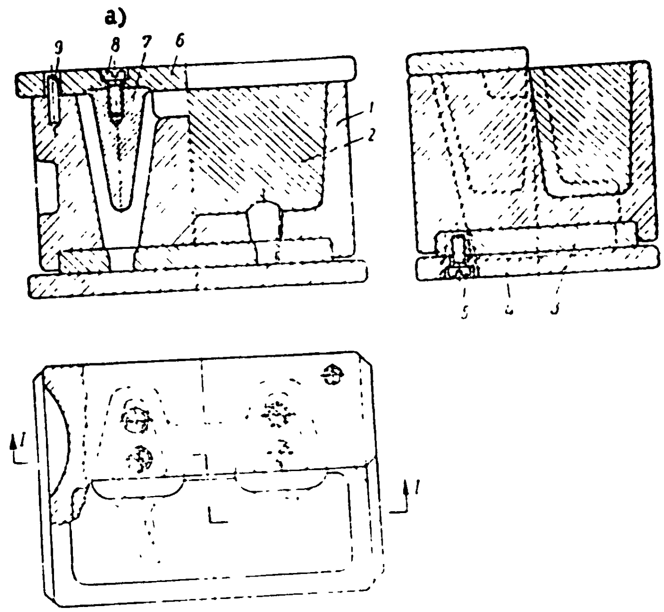

Fig.19 - Mold for Casting Mated Risers

1 - Matrix; 2 - Insert; 3 - Plate; 4 - Lower plate; 5 - Screw; 6 - Upper plate; 7 - Rod; 8 - Screws; 9 - Pin a) Section through I-I

The inner cavity of the jig is not finished with the same care as in a die, but must have a relatively smooth finish. Particular attention must be paid to the parting surface of the jig. It is important in all cases that the mass cannot flow out of the jig. Since it would be difficult to use special gaskets in this case, the property of the pattern mix of rapidly solidifying can be utilized. For this purpose,

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the jig must be made solid, or provision must be made for cooling it with cold water. A stepped or zigzag parting surface is recommended: in this case, if a small part of the mass extends to the parting surface, it will set rapidly, and its further leakage from the jig will stop by itself. The grooves between the pattern and the cavity of the jig should be made with particular care, since leakage of the pattern mix from the jig occurs mostly at these points.

A gating system made of pattern mix, because of being poured at atmospheric pressure, does not differ in smoothness from the surface of the pattern itself. Although perfect finish and smoothness of the surface is not needed on gates, since they perform only an auxiliary service and have no effect on the quality of the casting, efforts should be made to give the gates a certain degree of finish, which is accomplished by a rough cleaning of the section, assembled in the jig from a master pattern.

Jigs for casting can be successfully made by the method of precision casting from a hand pattern, made for single-time use from ordinary pattern mix. The finish of the casting corresponds fully to the requirements for finish of the gatings; in this case, only the parting line and the points of junction between jig and pattern need be machined.

Figures 19, 20 and 21 show a mold for casting risers, the jig for pattern assembly, and a block of assembled patterns.

V. THE FACING LAYER OF THE MOLD

Brief Information on Molding Materials

Before describing the technique of making the mold in precision casting, a brief review over the properties of molding materials will be given.

Casting molds are usually made of a molding mix containing sand, clay, and sometimes special binders.

A molding sand is called lean quartz sand if it contains from 2 to 10% of

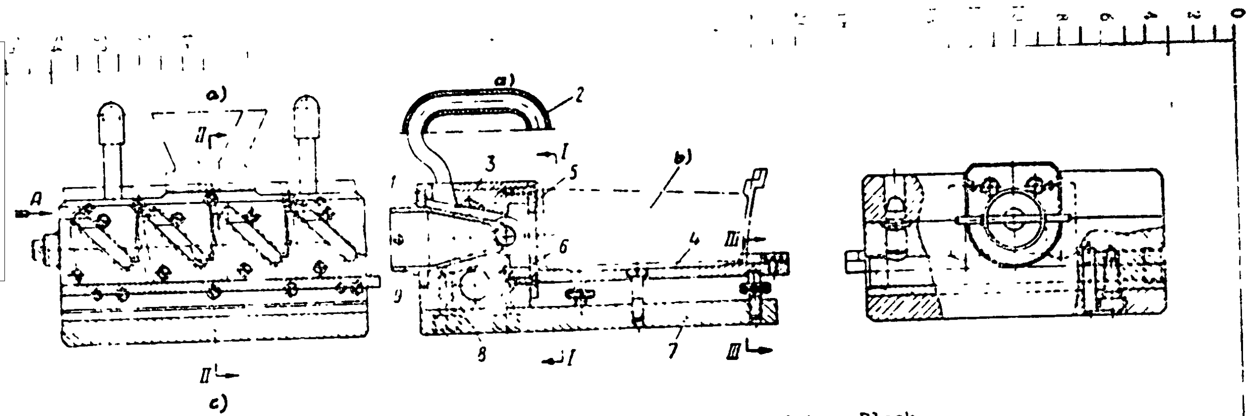

Fig.20 - Conductor for Assembly of Four Patterns into a Block

1 - End cap; 2 - Handle; 3 - Cover; 4 - Plate; 5 - Upper board; 6 - Low board; 7 - Plate;

8 - Body; 9 and 10 - Rod; 11 - Template a) Section through I-I; b) Pattern; c) View along arrow A

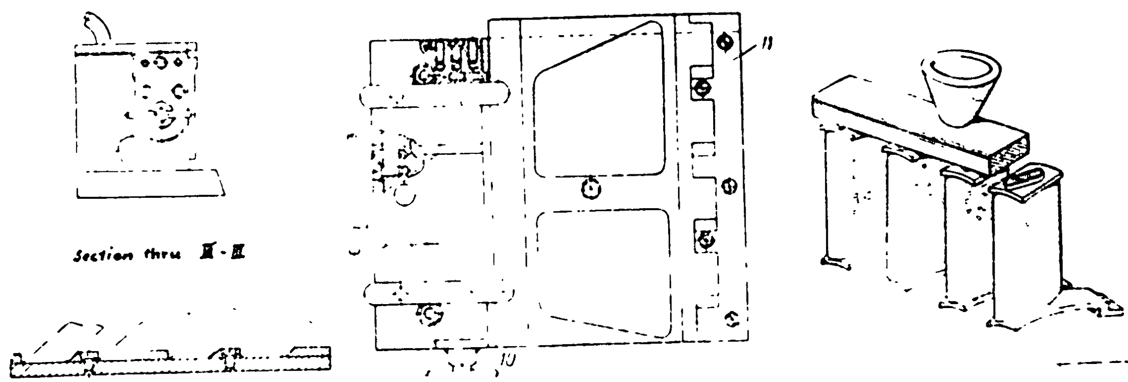

Fig.21 - Block of Assembled Patterns

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clayey ingredients, semifat argillaceous sand if it contains 20-30% of clayey ingredients, and fat loamy sand at 30-50%; a sand containing over 50% of clayey ingredients is called a loam.

A good molding mix must be plastic, strong, gas-permeable, and refractory.

The plasticity of a mix determines, to a large extent, the convenience of the molding process. This property of the mixture is very important for preserving the impression of the pattern. The more clay there is in a mix, the more plastic will the mix be; the shape of the granules of the mix also affects its plasticity.

The strength of a mold depends on the content of clay and water in the mix. A molding mix is stronger the more intimate the bonding of its individual particles. The strength of a mold also depends largely on the shape and roughness of the granules; the rougher the surface of the individual particles of sand, the more firmly will they adhere, and the stronger will the mold become.

The gas-permeability of a mold is important for unhampered liberation of water vapor in drying the mold and for proper discharge of the gases while teeming metal into the mold; such gases are evolved by the molten metal. The gas-permeability of a mold is greater, the lower the clay and moisture content in the molding mixture, the rounder the shape of the sand particles, and the greater the uniformity and size of these particles. The gas-permeability of a mold increases when it is dried, as a result of elimination of moisture from the mold.

Refractoriness is the term used for the ability of a molding mix to withstand the high temperature of the molten metal. This ability depends on the chemical composition of the mix and on the size of the sand grains. Larger sand grains fuse with greater difficulty, thus increasing the refractoriness of the mold.

Since the grain size plays an important role in the various properties of the molding mix, sand is usually graded in a screen with a definite mesh size (Table 3).

Preparation of Material for Facing Layer

As stated above, the facing layer of a mold in precision casting plays an excep-

Table 3

Characteristic of Screens for Grading of Molding Materials

(by GOST 2138-51)

Number of Screen	6	12	20	30	40	50	70	100	140	200	270
Size of mesh, in mm	3.3	1.7	0.85	0.6	0.42	0.30	0.21	0.15	0.105	0.075	0.053

tional and fundamentally new role in casting. The facing layer must be refractory, mechanically strong, and sufficiently smooth. A combination of these properties ensures accuracy and good finish of the casting.

For less important castings, a facing of quartz dust with a waterglass binder is sometimes used. This facing has not become very popular, mainly because of its low refractoriness. In series production, a facing of quartz dust with ethyl silicate and a binder is generally used.

<u>Quartz Dust</u>. Natural quartz dust (marshallite) is found in large quantities in the USSR in various deposits. Artificial quartz dust is prepared by crushing clean quartz sand in special ball mills with granite balls and lining.

Quartz dust consists mainly of silica (SiO_2), which runs up to 98% in particularly pure deposits and in artificial quartz dust. Natural quartz dust is a finely divided powder passing a No.140 screen (80-85%) and through a No.270 screen (40-50%). Natural quartz dust has a grain size No.140.

With respect to its SiO_2 content, quartz dust, from the point of view of precision casting, can be subdivided into high-grade and ordinary. The quality and purity of quartz dust largely depends on the presence of impurities, oxides of calcium, magnesium, iron, and alkali metals, which have an unfavorable influence on the properties of the facing layer. It has been found in practice that only high-grade quartz dust containing not less than 98.5% SiO_2, should be used for precision casting. The presence of more than 1.5% impurities causes spoilage in the castings and

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metal inclusions, adversely affecting the casting finish.

A similar influence on the quality of the casting is exerted by the grain size of quartz dust. The strength and refractoriness of the mold depends largely on the grain size. The theoretical studies as well as practical experience have proved that best result in strength and refractoriness of the mold surface as well as optimum finish of the casting, is obtained with quartz dust passing a No.270 screen. But the use of quartz dust of such fine grain size makes additional grinding of the large granules necessary. This operation requires special equipment and causes additional expense. Many plants have recently been successfully using quartz dust of grain size No.140 (as much as 85% of natural dust and as much as 95% of artificial quartz dust will pass through a No.140 screen). The finish of the casting in this case is only slightly poorer and, in practice, does not exceed the limits of the sixth class, specified in GOST 2789-51. Consequently, in series production there is no need for increasing the cost by an additional grinding of the quartz dust.

Before being put into production, quartz dust must be carefully freed of its various admixtures. This is done by washing it in running water in special sand washers or by elutriation in pans, with the upper layer of water decanted after settling. In the case of greatly contaminated quartz dust, it must be washed several times. The index of satisfactory purity for quartz dust is clean wash water.

Washed quartz dust is placed in refractory pans; after natural drying for final removal of organic impurities and also to reduce the subsequent shrinkage, the dust must be baked at 900°C for 2-3 hrs. This operation is usually performed in electric chamber ovens of the PN-13, PN-15 type. The fireproof pans with the quartz dust are charged into the oven, preheated to the assigned temperature. After the necessary time, the oven is emptied, the quartz dust is cooled to room temperature and sent to the screening department. Often, after baking, the quartz sand takes on a rosy tinge instead of its white color. This is due to the presence of iron oxides and is not a reason for rejecting the quartz dust.

Up to now, almost all plants grade quartz dust by hand, which is very labor-consuming; therefore, one of the Leningrad Research Institutes recently constructed a unit for sifting quartz dust (Fig.22). This unit should be used as widely as possible in all productive areas of precision casting.

Quartz dust should be sifted through a No.140 screen; a finer sifting through a No.270 screen gives a negligible advantage in the finish of the casting, which is not necessary, in series production.

Quartz dust has proved satisfactory as a filler for the facing layer. To eliminate a defect occasionally observed, namely cracking of the facing, the high-frequency metallurgical laboratory of the Leningrad Institute of Electrical Engineering has proposed the use of a facing which is practically free of shrinkage on subsequent baking. The filler for this investment is ground fused quartz. The use of fused quartz improves the quality of such facing layer. A step-up in the production of fused quartz will make large-scale use of this valuable filler possible.

Quartz Sand. In coating the pattern block with mold wash, each layer of the coating is sprinkled with quartz sand. The quartz sand used is of the lyuberetskiy type, brand K-50.100, washed free of impurities and baked like quartz dust, at 900°C. The baked sand, after cooling, is passed through two screens, No.40 and No.70. The sand remaining on the screen No.70 is used for the sprinkling. The so-called "white" (glass) Lyuberetskiy sand, which contains a minimum amount of harmful admixtures, has proved highly successful as sprinkling sand.

Ethyl Silicate. An organosilicon compound, ethyl silicate, is used as the binder for the facing layer. Ethyl silicate, mixed with quartz dust (in the following, this mixture will be called coating) covers the pattern with a thin elastic film which, after drying and baking, acquires mechanical strength and high refractoriness with a very high finish.

Without going into a detailed description of the methods of preparing ethyl silicate and of all its interesting properties, which is the subject matter of a new

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branch of chemical science, that of organosilicon chemistry, created by Soviet scientists under the guidance of K.A.Andrianov, corresponding member Academy of Sciences

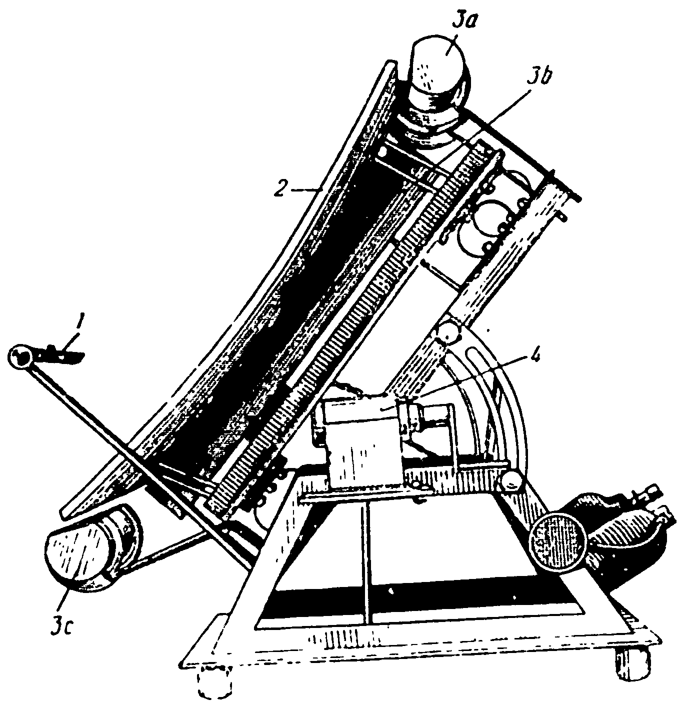

Fig.22 - Vibrator for Screening Quartz Dust

1 - Bracket; 2 - Sounding board; 3a, 3b, 3c - Bins for the Various fractions (3a for the finest fraction); 4 - Vibrator

USSR - let us consider ethyl silicate merely as a binder in the foundry industry.

Ethyl silicate is obtained by the esterification of silicon tetrachloride with ethyl alcohol, by the reaction

$$SiCl_4 + 4C_2H_5OH \rightarrow Si(OC_2H_5)_4 + 4HCl$$

Pure ethyl silicate is a yellowish-green liquid with the characteristic odor of

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ether. The percentages of the principal constituents may range from 28 to 42% SiO_2 and 0.05 to 0.15% HCl, and its specific gravity, at 20°C, from 0.92 to 1.0.

Among its other properties, ethyl silicate has the ability of forming viscous films. To obtain a binder product on an ethyl silicate base, capable of serving as a type of adhesive in the formation of a ceramic film from natural silicon dioxide (sand), ethyl silicate is subjected to hydrolysis. This means that the ethoxy groups attached to the silicon atom are saponified with water. As a result of this reaction, which takes place consecutively in several phases, consolidated molecules (polymers) are formed. According to the experience of many plants, 10 gm of water to 100 gm of ethyl silicate must be used for the hydrolysis of ethyl silicate (in other words, 1.2 mole of water per one mole of ethyl silicate). To prevent the formation of a gelatinous product during hydrolysis and to reduce the excessive concentration of SiO_2 in ethyl silicate, rectified ethyl alcohol of 92-96° strength, diluted with the calculated quantity of water, is used instead of pure water for hydrolysis.

Only 8-15% of the water present in the alcohol takes part in the hydrolysis, while the excess alcohol reduces the SiO_2 content of the ethyl silicate to a definite limit. The concentration of SiO_2 in hydrolyzed ethyl silicate is customarily adjusted to 20 ± 1%. A reduction of this concentration to 20% leads to a reduction in the thickness of the applied layer, due to a lowered viscosity of the coating, this requires an increase in the number of coatings applied and promotes stratification. An SiO_2 content of more than 20% in the ethyl silicate leads to an increase in the thickness of the layer, and may produce cracking of the film during drying, because of its excessive thickness.

The chemical industry formerly produced nonstandard grades of ethyl silicate, which differed markedly in contents of SiO_2, HCl, and volatile fractions. Practice has shown that any ethyl silicate produced by industry may be used in precision casting. However, in series casting on an industrial scale, this is very difficult whenever, in order to adapt to each new batch of ethyl silicate, the hydrolysis process must be modified and the drying conditions changed.

At present, the chemical industry is producing ethyl silicate for precision casting, within considerably more narrow limits. According to the specifications of the Ministry of Chemical Industry MKhP 2818-51, original ethyl silicate must contain 30-35% SiO_2, no more than 0.15% HCl, and no more than 3% of fractions with a boiling point up to 110°C. The specific gravity at 20°C must not be more than 1.0 and the viscosity at 20°, not more than 1.6 centistokes.

Delivery of a more stable ethyl silicate, not differing so much from batch to batch, unquestionably facilitates production and has a favorable effect on the quality of the product.

<u>Technology of Ethyl Silicate Hydrolysis</u>. Until quite recently, the hydrolysis of ethyl silicate was performed in the plants by simply mixing the original ethyl silicate in a glass bottle with dilute alcohol. This operation involves a large amount of physical labor and in no way met the increasing demands of series production. At present, the hydrolysis of ethyl silicate is extensively mechanized.

The following procedure is recommended: The ethyl silicate delivered to a plant (in one or more batches) is poured into a single large stainless steel vessel of a capacity up to 200 liters, provided with a simple gage cock (unthreaded). Before charging, the vessel must be thoroughly cleaned which is done by sandblasting. Care must be exerted to prevent moisture and dirt from getting into the ethyl silicate.

The raw ethyl silicate poured into the vessel must be agitated, after which the vessel is closed with an airtight cover (threaded, with a rubber or lead gasket). A sample of the raw ethyl silicate is taken in a stoppered flask for chemical analysis, the results of which are compared with the certificate for the batch or batches charged; the raw ethyl silicate is then put into production.

By a preliminary mixing of large batches of ethyl silicate, the varying chemical composition of the raw ethyl silicate is compensated, which allows production with uniform material for a relatively long period.

The quantity of water in the form of dilute alcohol, necessary for the hydrolysis of ethyl silicate to the prescribed content of SiO_2 and HCl in the hydrolyzed ethyl silicate, is determined from the SiO_2 and HCl content in the raw ethyl silicate.

Rectified 94-96° spirits are diluted to the necessary concentration with distilled water and are then filled, in a measured amount, into the hydrolyzer (Fig.23). A measured amount of the raw ethyl silicate is charged into the measuring cylinder of the hydrolyzer. The ethyl-silicate supply cock is then opened and the stirrer turned on.

Since the hydrolysis reaction of ethyl silicate proceeds under liberation of heat, a cooling-water jacket is provided in the hydrolyzer. The hydrolysis should be performed at a temperature not over 40-45°C, which is regulated by the rate of flow of the coolant and the rate of delivery of the raw ethyl silicate. After all the raw ethyl silicate has been mixed with alcohol, the agitation should be continued for 40 minutes to 1 hour. The hydrolyzed ethyl silicate must then be cooled to 20-25°C and drained into a glass bottle, closed with a ground-glass or rubber stopper. One of the plants has recently introduced a two-stage hydrolysis of ethyl silicate: first with acidulated water, and then with alcohol; the binder produced contains 16-18% SiO_2 and 0.2-0.3% HCl and its viscosity is 4.5-7.5 centistokes.

Opinions differ as to the time the hydrolyzed ethyl silicate must be left standing before putting it into production. Some enterprises use ethyl silicate only 2 hours after hydrolysis, while others prolong the period of storage after hydrolysis to 2 or 3 days. Numerous technological tests have established that ethyl silicate can be successfully used as a binder in both cases, but in the interest of greater stability of production and uniformity of the process, the period of storage, after hydrolysis, once established, should be maintained.

It is recommended that all hydrolyses be run daily at the same time, for

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instance from 9 to 12 o'clock in a quantity sufficient to meet the daily need, so as to be able to use the ethyl silicate on the following day from the beginning of work during the entire shift.

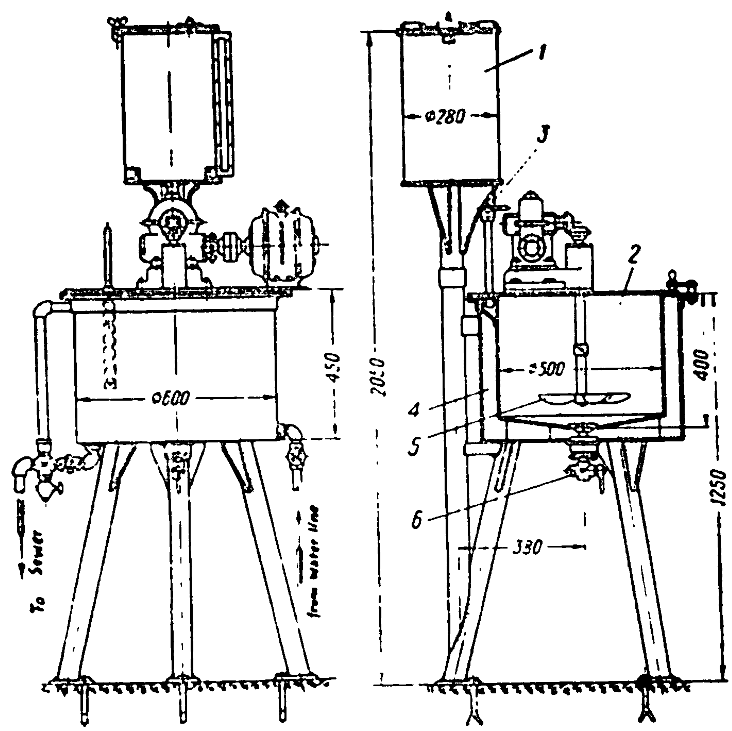

Fig.23 - Hydrolyzer

1 - Measuring cylinder; 2 - Hydrolyzer; 3 - Hose; 4 - Water-Cooling jacket; 5 - Stirrer; 6 - Drainage system

Below, we give an example for calculating the amount of alcohol necessary and its concentration for a given batch of ethyl silicate.

Assume that we have a batch of ethyl silicate containing 34% SiO_2 and 0.12% HCl. The amount of hydrolyzed ethyl silicate (binder) required for the following day is

12 liters.

Assume that the content of SiO_2 in the hydrolyzed ethyl silicate should be 20% and that of HCl 0.10%. Then the amount of ethyl silicate needed will be

$$\frac{12 \times 20}{34} = 7.06 \text{ ltr}$$

The amount of alcohol needed will be 12 - 7.06 = 4.95 ltr.

The alcohol should contain water in the proportion of 10 parts to every 100 parts of ethyl silicate, i.e., 7060 : 10 = 706 ml. Since 4940 ml of 94° strength alcohol already contain 4940 × 0.06 = 296 ml of water, water must be added in an amount of 706 - 296 = 410 ml.

The amount of chemically pure hydrochloric acid needed will be

$$\frac{12000 \times 0.1}{100} - \frac{706 \times 0.12}{100} = 3.5 \text{ ml}$$

About 10 ml $\left(\frac{3.5 \times 100}{36}\right)$ of technical 36% hydrochloric acid will have to be added.

Technology of Coating and Drying

The facing layer is applied to the block of patterns in the liquid state.

The coating is usually composed of 100 gm of quartz dust to 45-55 ml of hydrolyzed ethyl silicate. In this ratio, the minute granules of the quartz dust will be most completely coated by the binder particles. A high quartz content produces a more brittle and less strong film, and the coating obtained is thick and fails to coat all surfaces of the pattern. A higher binder content, on the other hand, makes the coating more liquid, and the facing layer less strong. A more accurate ratio between the quartz dust and the binder for each layer of coating is checked by the readings of an hydrometer.

Some plants add small amounts of glycerol and boric acid to the coating. Practice has shown these additives to be entirely unnecessary and to have no influence whatever on the quality of the facing layer.

[redacted]

The coating of patterns with the facing layers is performed by dipping the block in the liquid coating, which is continuously stirred. For the time being, this must be considered the most efficient, since coating by dust applicator is not feasible (the dusting machine would immediately become clogged), coating by brush would not give a layer of uniform thickness. In many plants the coating is made up and stirred by hand, which does not give a satisfactory and uniform layer of the coating.

There are a number of mechanical mixers available for the coating. Figure 24 gives a diagram of one type. The mixing is performed by means of an electric drill to which a paddle-wheel is mounted. The coating is stirred periodically. While the pattern is being dipped, the stirrer is removed from the coating bath (this, as well as the bulk of the installation, are drawbacks of this design).

At one of the plants, a new type of mechanical mixer, an electromagnetic mixer, is now being tried out. Here the coating is mixed by an electromagnet at the bottom of the bath. The magnet is provided with paddles which, during the mixing, whirl the particles of liquid coating upward. The magnet is actuated by another powerful magnet, turned by an electric motor installed underneath the bath. A mixer of this type operates continuously and does not interfere with dipping of the patterns, which are loaded into a wire net basket.

In order to strengthen the facing layers, improve their bonding, and prevent cracking, each layer of coating is sprinkled with quartz sand. There are several types of mechanical sanders available for this operation. For instance, in one of them (Fig.25) a drum into which baked quartz sand is sprinkled, rotates inside a metal shell. When the drum rotates, the vanes scoop up the sand and carry it upward; when reaching the top, the sand falls off. The rotating drum contains a No.50 mesh, likewise in the form of a drum, but fixed. The coated pattern is placed inside the screen drum and is sprinkled with the sand trickling downward.

Figure 26 is a diagram of an elevator sander, and Fig.27 is a general view of a sander in which the screen is actuated by a pneumatic pushrod.

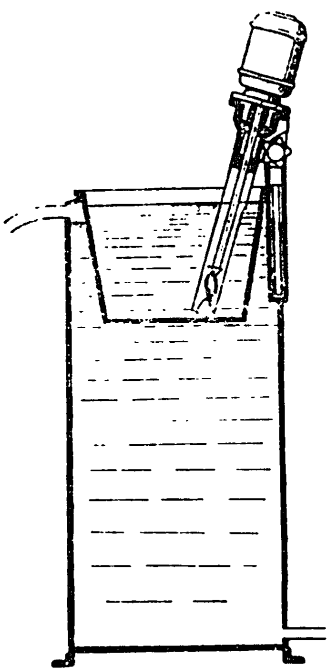

Fig.24 - Mechanical Mixer

for Coating

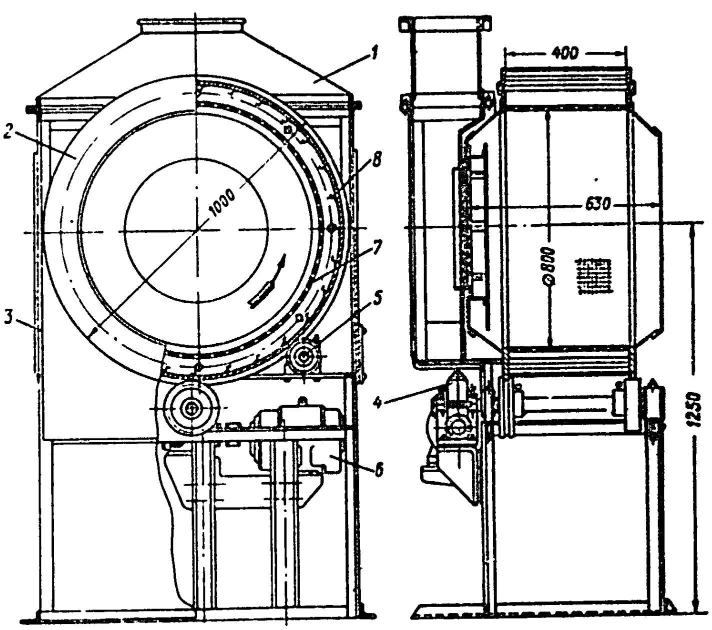

Fig.25 - Drum-Type Sander

1 - Vent Hood; 2 - Drum; 3 - Frame; 4 - Reducer; 5 - Roller;

6 - Electric motor; 7 - No.50 screen; 8 - Vane

Only a very short time ago, each layer of coating applied to a pattern was naturally dried after sanding, for 12-18 hrs, which greatly extended the production cycle and made additional fillings of defects necessary between the operations. In addition, the prolonged drying cycle tended to increase spoilage (cracking of the layers) owing to nonuniform drying conditions.

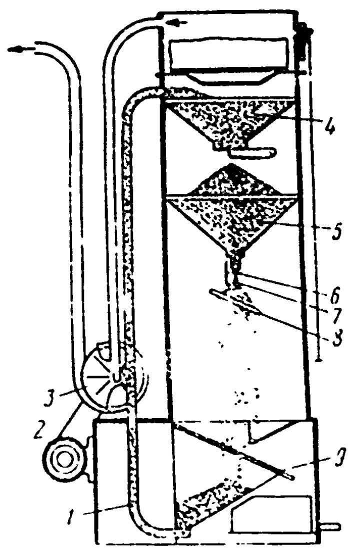

Fig.26 - Elevator Sander

1 - Elevator pipe; 2 - Electric motor; 3 - Fan; 4 and 5 - Bunkers; 6 and 7 - Dissector; 8 - No.50 screen; 9 - No.80 screen

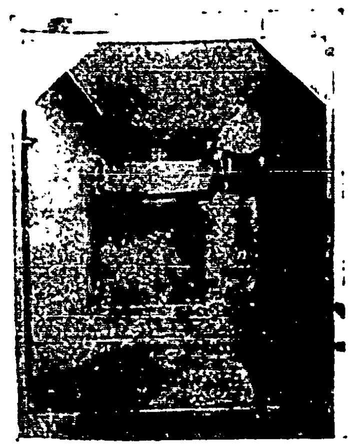

Fig.27 - General View of Pneumatic Sander

In order to shorten the drying time of the facing layers, drying the coated blocks in an ammonia atmosphere was tested a few years ago. The drying period in ammonia vapor was shortened from 12-18 hrs to 10-40 min.

Today it is known that ammonia vapor not only shortens the drying, but also considerably improves the quality of the facing layer formed. The ammonia vapor encour-

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ages a more uniform progress of the residual hydrolysis processes throughout the entire thickness of the film while, with natural drying, these processes concentrate more in the outer layer of the film, which often leads to cracking of the film.

For sanding the facing layer on coated blocks in an ammonia atmosphere, the installation shown in Figs.28 and 29 may be recommended. A hermetically closed box is connected with an ammonia cylinder. With the closed piston extended during the established time, the ammonia is delivered to the box at a definite rate through a flow meter (0.5 liter per minute, at a box capacity of 250 liters). After this, the admission of ammonia into the box is stopped (the cylinder is closed), and the coated patterns are kept there for an additional period; then, the fan is turned on and the patterns are removed from the box. The ammonia consumption and the ammonia drying time are selected for each part individually.

The following conditions of ammonia treatment can be recommended for patterns with a coating area of up to 400 cm^2:

Natural drying after coating	5-40 min
Residence time of patterns in ammonia stream	5 min
Rate of ammonia discharge	0.5 liter/min
Hay in drier without addition of ammonia	5-10 min
Natural airing after ammonia drying	10-40 min.

Thus the technology of coating and drying pattern blocks comprises:

1. Dipping the pattern block in the coating. The block is held with the right hand (use rubber glove) by the pouring cup, and, if necessary, with the left hand by the riser part; the block is dipped 3-6 times, after which it is removed from the coating and placed under a sandblast in the sander (while being dipped into the coating bath and sanded, the pattern block is uniformly rotated, so as to prevent build-up of the coating and to obtain a smooth and uniform facing).

2. Natural drying and ammonia treatment of a batch of coated blocks according to the established conditions.

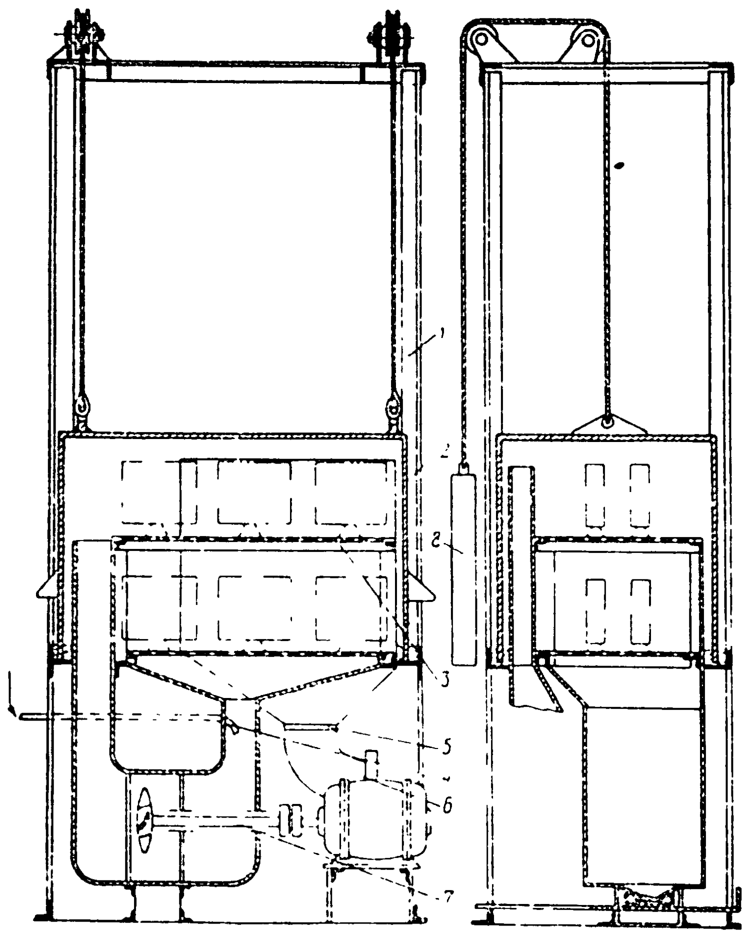

Fig.28 - Installation for Ammonia Drying of Coated Patterns

1 - Frame; 2 - Cap; 3 - Removable grating; 4 - Ammonia nozzle; 5 - Exhaust; 6 - Bend; 7 - Circulating device; 8 - Weight

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In this step, four layers of facing are applied with the coating, sanding, drying, and ammonia treatment of each layer being performed in the same manner. The density of the coating (according to hydrometer) for the first layer should range from 1.685 to 1.695, for the second from 1.65 to 1.67, and for the third and fourth, from 1.6 to 1.62.

Fig.29 - General View of Simplest Installation for Ammonia Drying

The configuration of some parts requires additional strengthening of the facing layer, particularly in spots that are not convenient for the shaping process. For this purpose, the patterns are greased in some areas. The composition of the grease is as follows (in parts by weight):

Hydrolyzed ethyl silicate	50
Quartz sand	99.5
Magnesia	0.5

The greasing is done ad libitum, but the quartz sand is mixed in advance in with the magnesia in small runners. The patterns need be coated with lubricant only at the places requiring it, i.e., at spots needing additional strengthening. The lubricant, on a completely coated and dried block of patterns, is applied by hand, using a rubber glove, after which the blocks are dried naturally for 40 minutes to 1 hour, and are then treated with ammonia for twice the usual period.

A few practical remarks on applying the facing layer are given below.

The bath for make-up of the coating must be of stainless steel, and after each pouring the coating residues must be thoroughly cleaned and sandblasted. The size of the bath must be selected in accordance to the size of the pattern block, since

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this has a noticeable influence on the consumption of ethyl silicate and coating.

Coating previously used for the top layers of the facing should not be used for the first facing layer of patterns, since such coating always is contaminated by a certain amount of quartz sand from sanding the patterns, so that the first layer will not be satisfactory. The pattern blocks should be coated in succession with one and the same coating, always using fresh coating for the first layer.

Thinned coating, if carefully stored, can be used for all layers after the first layer, over a period of two or three days. The first layer must be applied with freshly prepared coating.

In order to thin fresh coating, it must be allowed to stand not less than 30 minutes to eliminate the air bubbles entrained by the quartz dust into the coating. A check must also be made (by hand, in a rubber glove) that the coating contains no unmixed lumps of quartz dust.

In coating patterns with inner cavities, the inner cavity must be cleaned of excess sand after sanding, before applying the next layer. For this purpose, bristle brushes may be used. The excess sand must also be cleaned off the block from outside, by means of the brush.

The poorly coated spots on the gating, by which the pattern is held during the coating, must be given an additional brush coat. It may be recommended to fuse a special rod into the gating in which the handle is revolved during the coating process. The piston may then be removed after the coating is done, by using an electric soldering iron. After the coated blocks are delivered for shaping, the face of the gating must be thoroughly cleaned of drops of coating and sand.

The process of applying the facing layer to the pattern block is one of the most important operations in precision casting. This must be done with extreme care. The coating is checked from the condition of the film. On the first pattern coated (without the riser) the quality of the coating is checked. Each layer of the coated blocks is checked, after the ammonia drying, for absence of fissures and peeling of

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the facing from the pattern surface, produced by tension of the film. This test is made by light pressure of the finger on the coated pattern. Defective blocks are not further processed.

VI. MOLDING DISPOSABLE PATTERNS

Molding in precision casting differs somewhat from that ordinarily practiced in foundry production. As stated above, the molding of disposable patterns is conducted by two methods, the dry and the wet.

Only very recently a very interesting method of mold making was proposed, using a double facing and making molding unnecessary, and, therefore, considerably shortening the production cycle. The pattern block, coated with the facing layer, is then subjected to three additional applications with the following composition: 70% quartz dust of grain size No.100-120, and 30% waterglass of sp. gr. 1.2. The pattern clusters are coated by the same method used for the original facing layer, and the coated layers are then sanded with course quartz sand, with intermediate natural drying for 2-4 hours. The mold is then ready for the following operations, melting out, firing, and pouring.

This method has not yet been widely adopted, and at the present time the molding of diposable patterns by the methods described below is used in precision casting.

Dry Molding

Dry molding is applicable to parts not requiring high accuracy in view of the unstable shrinkage of the main filler, quartz sand. Recently a new facing fused quartz, has been proposed for dry molding by the Leningrad Institute of Electrical Engineering (High-Frequency Metallurgical Laboratory). This material is practically shrinkage-free, but its use is still limited, since there is no industrial production of fused quartz.

The following materials are used as dry filler for the mold in precision casting:

a) Quartz sand K 50/100 98-99%

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Borax or boric acid	2-1%
b) Chamotte lumps	98-99%
Borax or boric acid	2-1%
c) Ground fused quartz	98-99%
Borax or boric acid	2-1%

When the first two of these fillers are used, the dimensions of the casting in length are inconstant if shrinking is inhibited. Fused quartz, as already stated, behaves well with respect to volume variations; it requires the use of materials prepared from fused quartz for making the facing layer.

There are two methods of molding, using a dry filler:

Molding in Flasks with Refractory Bottom Plates. The refractory bottom plate is heated to a temperature of 100°C and a layer of the pattern material is applied to it. Usually the plate is rubbed with a lump of the material, but a liquid layer of the material can also be poured on. Then the face of the tun dish of the pattern block is placed on the bottom plate in such a way that the face of the dish closes the opening in the pan. When the pattern material hardens, the pattern block is rather firmly cemented to the pan. A refractory flask (cast or welded of material sheet) is next placed on the pan in such a way that equal clearances are left between its walls and the pattern cluster. The flask is then sprinkled with the pattern mixture, whose components are mixed in advance on crusher rolls. The filler in the mold is settled by lightly tapping the cast with a hammer or by cautious ramming.

The flask, filled to the top, is then covered with a second refractory pan having no openings. The lower and upper pans are attached to the flask with wire. In this state, the mold (Fig.30) is ready for the next operations, melting out the pattern mixture, firing, and pouring.

Molding in Flasks with Moist Plugs. In this method of molding, the refractory pans are replaced by a moist mixture of quartz sand (90%) and waterglass of sp. gr. 1.2 (10%).

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On the flask board the pattern cluster is placed by the face of the pouring cup. The board also carries a boxlike refractory flask. The bottom of the mold is filled to two thirds of the pouring cup with the moist mixture of quartz sand in waterglass. The mixture is rammed lightly. After this, dry filler is sprinkled into the flask, and the upper part of the mold (20-30 mm) is filled with the same mixture of quartz sand and waterglass, by lightly ramming. In two or three hours the plugs harden, and the mold, removed from the pan (Fig.31), is now ready for the next operations. For better parting of the mold from the flask board, it is recommended that the latter be lubricated with liquid machine oil.

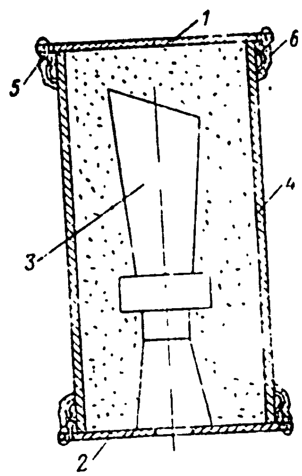

Fig.30 - Diagram of Molding Dry Filler and Refractory Pans

1 - Closed pans; 2 - Pan with opening; 3 - Pattern; 4 - Flask of refractory steel; 5 - Binding wire; 6 - Clay Coating.

The use of a dry filler for molding has the advantage of shortening the production cycle since, in this case, prolonged drying of the molds becomes unnecessary. In addition, the dry filler, regenerated with new binder (borax, or boric acid) can be re-used, which considerably cuts transporation costs and cheapens production.

For castings requiring high dimensional stability, however, a facing of quartz sand and grog is unsuitable, while fused quartz is not yet industrially available. For this reason, the method most widely used in precision casting today is the wet method of molding, using alumina cement as the mold binder.

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Molding with Wet Filler

In wet molding in flasks, the assembly of the patterns proceeds in almost the same way as in molding with dry filler.

The flasks used are mainly of the box type and are welded of stainless steel sheet 1.5-3 mm thick or cast of refractory steel with walls of 4-6 mm thickness. In series production, cast flasks are preferable, since they are less deformed in firing and pattern removal, and have a longer service life. The inside dimensions of the flasks must correspond to the pattern clusters being molded. The extreme points of the patterns must be not less than 20-25 mm from the edge of the flask. The upper cut-off line of the flask must be located not less than 30 mm above the cluster being molded. For convenience in transporting the hot molds, special hooks or lugs of stainless steel are sometimes welded to the larger flasks.

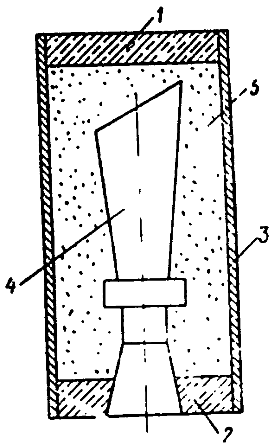

Fig.31 - Diagram of Molding with Wet Plugs

1 and 2 - Plugs of Moist Filler; 3 - Flask; 4 - Pattern; 5 - Dry filler

In the centrifugal method of casting, the flask must meet higher requirements, since the position of the flask determines the position of the part during casting in the centrifugal machine. The welded flasks for the centrifugal machine must be more carefully oriented after each filling. Special marking holes are sometimes drilled in the flasks to indicate the position of the pattern block in the flask, if the block is not symmetric.

When the molds are fired at 900°C, the material of the flask expands less than the ceramic of the mold. This sometimes leads to cracking of the mold. To avoid

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damage during assembly of the mold, inserts of paper or cardboard of 0.2-0.3 mm thickness are used, and are placed at the walls of the flask during molding.

With this in mind, Academician A.A.Mikhulin proposed an interesting flask design. In studying precision casting in collaboration with Engineer S.D.Bogoslovskiy, he encountered cracking of the molds due to the difference between the coefficient of expansion of the metal of the flask and that of the ceramic and proposed an original design of ribbed (corrugated) flasks. On heating, the ceramic mixture, while expanding, presses down on the flask, whose corrugated surface, as it were, becomes flattened. This gives a favorable effect only when the thickness of the flask material is small (up to 1.5 mm). At greater flask thicknesses, the corrugation does not work satisfactorily.

Flask boards are usually cast of aluminum alloys. They are sometimes made with a crimp when the sections are cemented to each other by molten pattern mixture. It is advisable to cement a marker for affixing the pattern block, to a predetermined spot, which will fix the position of the block relative to the board and the flask.

Molding Materials. Quartz sand and alumina cement are used as wet filler for molding.

Quartz sand, brand K 50/100 or K 40/70, is the principal mold filler in precision casting. It has good molding properties and is the most available molding material. The use of quartz sand with a minimum clay content (up to 1.5%) is explained by the need for relatively high refractoriness of the mold in precision casting, since it is fired at a temperature of 900°C. The requirement of a definite grain size (50/100, 40/70) is dictated by the results of experimental work which showed this grain size composition to be the optimum size; if the sand contains coarser or finer particles, the mold becomes less strong and tends to develop cracks during drying and baking.

Quartz sand is subjected to a preliminary treatment, consisting of drying, sometimes of firing for 1-3 hours at 750-900°C and sifting through a No.40-100 screen.

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The drying of the sand is necessary to improve stability during molding, since the use of moist sand prevents proper mixing of the dry components and preparation of a uniform molding mixture. The firing serves to remove the organic impurities from the sand.

Alumina cement is used as a binder. This type has the property of hardening more rapidly than any other types of cement. There are three grades of alumina cement, depending on its strength properties (Table 4).

Table 4

Properties of Alumina Cement

Grade of Cement	Ultimate Tensile Strength in kg/cm^2		Compressive Strength in kg/cm^2	
	After 24 Hours	After 3 Days	After 24 Hours	After 3 Days
300	16.0	18.0	250	300
400	20.0	22.0	350	400
500	24.0	26.0	450	500

All grades of alumina cement can be used in precision casting, but intermixing of batches is not recommended. If the grade of alumina cement used in production is changed, the new cement must first be tested, and, if necessary, the technique of molding must be corrected with respect to the amount of water and cement in the mixture, and the time of drying.

Before being put into production, the cement must be passed through a No.70 screen.

Alumina cement is a highly hygroscopic material and must therefore be protected from moisture and stored in a dry room.

Preparation for Molding. The filler is prepared in ordinary solution mixers or in special mechanical mixers (Fig.32).

The composition of the facing is as follows:

Quartz sand	80-90%
Alumina cement	20-10%
Water	30-40% of dry mixture by volume

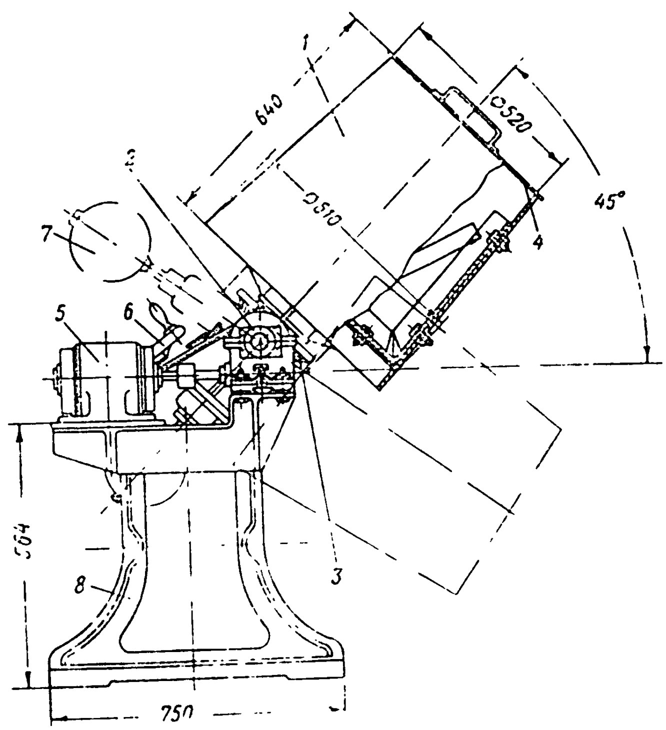

Fig.32 - Mixer for Preparing Liquid Mold Mix

1 - Drum; 2 - Worm reducing gear; 3 - Turning mechanism; 4 - Cover;

5 - Electric motor; 6 - Tilting Knob; 7 - Weight; 8 - Base

The wide range of alumina cement content is explained by its varying strength properties: Grade 300 cement is added to the slurry up to 20%, while it is sufficient to add 10-12% of grade 500 cement.

Some plants use small amounts of ground grog, waterglass, or calcined sodium carbonate in the facing. The addition of these components has no influence on the improvement of the facing and therefore should not be added.

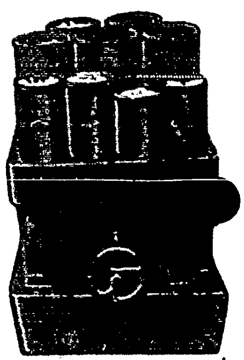

Fig.33 - Vibrator with Molds in Position

The sand and cement are sprinkled into the mixture with measuring rings. First, the dry mixture is mixed and then water is added, and the facing is mixed until completely uniform. In mechanical mixers, the mixing time for the facing slurry does not exceed 10-15 min, after which the slurry is removed and taken to the molding site.

The molding of flasks by facing slurry is made on a jolting table called a vibrator. The time from the beginning of molding to the end of utilization of the batch is limited to 20-30 min.

<u>Types of Vibrators and Molding</u>. There are several types of jolting machines. According to their mechanisms, vibrators may be pneumatic, mechanical (eccentric), or electromagnetic. The amplitude of vibrations of the vibrator table is 0.1-0.2 mm, and the frequency of the vibrations is 1500 cycles a minute. The amplitude of the vibrations should not be increased above 0.2 mm, since this may lead to breaking the patterns during molding; however, a reduction in the vibration amplitude of the shaking table requires a longer vibration treatment.

The prepared molds are placed on the vibrator (Fig.33) a few pieces at a time, depending on the size of the molds and the capacity of the vibrator.

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The flasks are filled with facing slurry to the top, and the vibrator mechanism is turned on. As the slurry settles into the mold, more slurry is added to the flask with a shovel. The vibrator is provided with beads and a slurry bin, into which the excess of slurry is discharged.

For each part, the vibration time must be strictly determined, since the vibration period affects the mechanical strength of the mold and, as a result, also affects the dimensions of the casting, in connection with the hampered shrinkage of the metal. It is recommended that the vibration time be measured by means of hour glasses; depending on the size of the mold, this is 3-10 min or more (for larger molds); for all parts of the same kind, the vibrations time must be strictly the same, to prevent a difference in the geometric dimensions of the castings.

In molding, the workman must check correct filling of the mold from time to time. Sometimes a special spatula must be used to pack difficultly accessible places (cavities). Particular attention must be paid to the integrity of the patterns during molding, since the pattern material has a low mechanical strength, and if molding is not done correctly, the pattern cluster may be damaged.

After the vibration process has been completed, the molds are removed from the shaking table and placed on a rack for natural hardening and drying.

The mechanisms and room must be cleaned as soon as the molding has been finished, to prevent rapid setting of the left-over slurry, which makes subsequent cleaning very difficult.

Flaskless Molding. The use of fire-resistant steel flasks, which makes it necessary to afterbake the molds at 900°C, substantially increases the production cost of precision castings. Flasks of sheet metal rapidly become deformed, and, as a rule, are badly burned out after 5-8 cycles and become unfit for further use. The use of cast flasks prolongs their service life but considerably increases the weight of the mold. For this reason, it is logical to attempt to relieve the production process from flasks and to introduce a method of flaskless molding or to replace the

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flask material by a cheaper one.

Many plants and scientific institutes have conducted experimental studies with this in view; at the present time, one of the plants has already been successful in developing a method of wet flaskless molding, using frames. The pattern cluster is mounted on the flaskboard in the same way as in ordinary molding. A separable iron flask is then placed on the board. In this, a frame of 2.0-2.5 mm diameter wire is installed, of the type used in core-making. The frame is set so as to be 5-8 mm away from the walls of the flask and from its upper edge.

The molding is done with a slurry containing 81% quartz sand, 19% alumina cement and 30% (by volume of the dry mix) water. After the mold has hardened and the lower edge of the flask has been cleaned, the flask is removed from the mold, and all subsequent operations are performed on the molds without the flask.

The frames, with a slight amount of overhauling, are used repeatedly. In the case of small molds (120 × 120 × 120), the frames may be dispensed with.

Preparation of Molds before Melting Out. The alumina cement already hardens in the first hour after molding. However, for complete hardening of the mold and for giving it the necessary mechanical strength, a period ranging from 16 hours for small molds to 48 hours for large ones is necessary.

The process of hardening of the molds depends to a considerable extent on the temperature and humidity of the air in the room. The most favorable conditions are a temperature of 15-25°C, at a relative air humidity of 30%. Cases are known where, at a low temperature in a damp room, molds did not set for several days.

The molds, after sufficient hardening, are separated from the flask boards by a light tap of the hammer on the board. With a knife, the pattern material is thoroughly removed from the lower face of the mold, and the face of the tun dish is also cleaned. If the mold is well hardened, its lower edge becomes very smooth and even. This is a prerequisite since, while firing the mold followed by teeming the metal, the mold material (ceramic) may become penetrated by metal if the surface of the mold face is uneven.

The molds so prepared are now ready for the operation of melting-out the pattern material.

VII. MELTOUT OF PATTERN MATERIAL FROM THE MOLD, DRYING AND FIRING THE MOLDS

Melting-Out the Pattern Material

The pattern material is melted out of the mold by means of hot air, steam, or in special thermostats.

Sometimes the melting out of the pattern material is combined with drying and even with firing; in the latter case, what is done is not to melt out the pattern material, but to burn it out of the mold. The burning out of the patterns involves high losses, since the pattern material is entirely consumed by fire and cannot be further utilized. Burning out may be considered justified when the fusion point of the pattern material is high and is close to its flame point (plastics), or when it contains highly toxic, harmful substances of the type of holowax, whose vapor has a toxic effect on the human organism. In this case, the operation of drying the molds is combined with that of firing, with the object of reducing the sources of toxic vapors.

Steam under a pressure of 0.5-1.0 atm is fed to a special plate with nozzle openings, over which the molds are placed, pouring cup down. Under the action of the steam, the pattern material melts and flows with the condensate out of the cavity in the molds. Since the specific gravity of the pattern material is less than unity, it is easily separated from the water, floating to the top and solidifying in the collector like a layer of ice.

It is very convenient to use steam for melting out the pattern material from the mold, for a low-melting pattern material with a melting point not over 80°C. This method is not applicable to higher melting compositions; in this case, the

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melting out is done by means of hot air and in special drying cabinets. When cabinets are used, they must be inspected for cleanliness, since all channels for removal of the pattern material may rapidly clog with molding material.

If the meltout of the patterns is done with steam or hot air, a hood must be placed over the spot, and the working place must be connected with a forced ventilation exhaust.

Drying the Molds

After melting out the pattern material, the molds contain a large amount of moisture, which is removed by drying. The molds are dried either in conventional electric chamber batch driers, or by special methods. The former type of driers use heating in stages, while in the latter type the temperature is set in advance for the entire duration of drying.

For molds of an average weight up to 30 kg of molding material, the following drying conditions are recommended: increase of temperature to 50°C and holding at this temperature for 6 hours, to 90°C, 4 hours; to 120°C, 3 hours; to 150°C, 3 hours; to 180°C, 2 hours; to 210°C, 2 hours; to 250°C, 2 hours. The total duration of the drying is thus 22 hours; for smaller molds, this time may be somewhat shortened.

It is desirable to charge the molds into the firing ovens as soon as they are dry; this is easy to do when using heating installations in which the baking oven is, as it were, an extension of the drier. The molds in this case are transferred by simply pushing the pan with the molds from the drier into the baking oven. If drying chambers and ovens are used, such a transfer of molds is impossible, and therefore the processes of drying and baking must be so planned as to shorten the transfer time of the molds as much as possible.

Transfer of the molds from the drier to the oven could be entirely avoided by using a single long installation, but this is impossible in practice: The result would be a very long oven and, in addition, the temperature at the exit would always be considerably higher than 50°C, since it is very difficult to establish a temperature drop from 900°C to 50°C in a single oven.

Unloading the molds, dried to 250°, onto the ground, their cooling, and subsequent charging for the firing would be undesirable, since a rapid cooling from a high temperature followed by a rapid heating of the ceramic mold, might result in cracking of the mold. If, because of the necessities of production, a delay in charging the molds for firing is unavoidable, it is preferable to place the molds, until their transfer, in a drier at 250°C (the time of storage of the molds at 250°C need not be limited). If, however, unloading of the molds from the drier is absolutely necessary, and a time interval before firing the molds is proposed, then the molds must be unloaded, at 150°C rather than after completion of the drying cycle at 250°C, followed by drying for the remaining stages in the oven (not in the drier). In this case, cracking of the molds is considerably reduced.

Firing the Molds

The molds are fired in electric chamber ovens or in continuous ovens.

In small-scale production, ovens of the type PN-12, PN-13, and PN-15 are often used. In working with these ovens, the firing of the molds proceeds stepwise. In large-series or mass production, a continuous pusher oven should be used. In these ovens, the temperature conditions are assigned in advance and are kept constant over the entire length of the oven.

For a mean mold size of up to 30 kg of mold material, the following firing conditions are recommended: loading the molds into the oven preheated to 250°C, holding at this temperature for 2 hours; increasing the temperature to 350°C, 2 hrs (including time at this level); to 500°C, 2 hours; to 600°C, 2 hours; to 700°C, hour; to 800°C, 1 hour; and to 900°C, 4 hours. The entire firing cycle lasts 14 hours. If it is necessary to hold the mold in the oven during the time of pouring, the mold must not remain for more than 12 hours in the oven at a temperature of 900°C.

As shown above, the drying and baking of molds formed with a facing slurry takes a long time at very slow temperature rise. This is explained by the presence of large quantities of water in the mold. The vapor formed by this water might break the form and cause cracks if rapidly heated, which would be entirely impermissible for precision casting of parts. The surface of such molds exhibits many grooves; the metal poured into such a cracked form runs into the cracks and might completely run out of the mold. On slow heating, the water vapor leaves the mold gradually, without breaking it.

Naturally, molds molded with a dry facing are processed considerably faster. In this case, there is no drying at all, the molds can be placed in the firing oven at 600°C, and the increase in temperature to 900°C, together with the residence time of the molds at this temperature, is cut to 6-8 hours (without any residence at the intermediate temperatures). Molds with a double facing, without any filler, can be treated in the same manner.

This shortening of the drying and firing cycles (from 30-36 hrs to 6-8 hrs) and, consequently, the shortening of the productive cycle, and the considerable saving in electric power, are the obvious advantages in using a dry facing or molds with a double facing.

Heating Devices for Drying and Baking Molds

Driers. Electric chamber driers are of very simple design, consisting generally of an iron framework with tightly closing doors. The framework used is of the double type, containing a heat-insulating material between its walls (rock wool, asbestos, diatomataceous earth).

In some driers, fixed racks with openings are used on which the molds are loaded. For charging and emptying, such driers are less convenient than driers with sliding drawers.

Several types of heaters for driers are in existence. Heating coils are sometimes placed beneath the lowest rack of the drier. When a sliding drawer system is used, this arrangement of the heating coils cannot be used; in addition, a great

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temperature difference exists in this case at the various levels of the drier. Electric coils may be placed along the three inner walls of the drier over its entire height. This results in a more uniform temperature in the drier. An electric radiator has proved satisfactory. This is usually placed above the drier. In this arrangement, the drier is heated by a jet of air propelled by a fan through the heater into the drier.

If drying the molds is combined with meltout of the pattern material, provision must be made in the frier for removal of the pattern material. For this purpose, special receptacles, with an outlet to the outside, are sometimes placed under each shelf of the drier. Excessively long connections between the pipes, sometimes used for centralization and discharge of the pattern material into a single opening during the drying process, should be avoided, since too long a path traveled by the melted pattern will complicate the operation. Such pipes will become fouled with molding and pattern material.

The continuous pusher drier is the most convenient form of equipment for mold drying. Here the molds are placed on pans which are pushed every hour through the drier. The temperature at the entrance to the drier is 50°C and the temperature at the exit from the frier, 350°C. The total length of the drier is 8-12 m. The drying cycle lasts 18 hours. The drier is provided with pyrometric instruments for regulating the temperature in three zones. At full heating of the drier and continuous operation, the first zone is usually turned off, since the inlet temperature is maintained at its proper level by the heaters of the other two zones. The drier must be ventilated. A duct above the drier, connected to an exhaust fan, is suitable only if the pattern material is melted out of the molds before charged into the drier. If the meltout takes place entirely within the drier, the liberated gases will have to be removed through a flue.

<u>Ovens for Firing the Molds</u>. In small-scale production, as already noted, electric chamber ovens of the type PN-12, PN-13 and PN-15 can be used for firing the

mold. All these ovens operate well at temperatures up to 900°C. For a more uniform firing of the molds in the immediate vicinity of the charging door, the door itself must be heated by placing heaters on its inside, fed by flexible cables. The regular brick floor of these ovens should be covered with cast refractory pans, with ribbed guides for the molds.

If the door is not separately heated, the two front rows of molds will be inadequately fired, because of the suction of air underneath the door. In this case, loading the molds all the way to the door is not recommended. Between the front rows of molds and the door, a wall of crushed brick should be built slightly higher than the molds, and the bottom of the oven door should be sprinkled with sand.

To make maximum use of the sole of the baking ovens, the molds are loaded in two rows, one after the other. Practice has shown that this is entirely practicable for molds weighing up to 20 kg, without involving loss in product quality. In this case, more accurate loading and unloading of the molds is necessary, using special devices (Fig.34). This method of loading increases the throughput of the firing kilns by 40%.

A continuous pusher firing oven produces the best results in mold firing. A description of an oven of this type, in operation at present, is given below (Fig.35).

The dimensions of the working surface are 7460 × 1100 × 600 mm; the pushing interval, one hour; the inlet temperature of the oven is 350°C, and the outlet temperature 900°C. The heaters, mounted in individual sections to the walls of the oven are easily replaced if necessary.

There are four zones over the entire length of the oven, in which the following temperatures are maintained by the pyrometric device (thermostat): 420°C in the first zone, 500°C in the second zone, 720°C in the third zone, and 900°C in the fourth zone. The first zone operates only during the initial warming-up of the oven, after which it is usually turned off, since the temperature of 350°C at the

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furnace entrance will be maintained by the heaters of the second, third, and fourth zones. Very often, during operation, the second zone is also turned off, while the third and fourth zones operate continuously. Repeated tests have shown that the heating of the molds in this oven is very uniform.

Fig.34 - Unloading Molds from the Firing Oven by Means of a Special Oven Fork

If the pattern material was first melted out of the molds, then ducts from an exhaust fan are installed over the doors for ventilating the firing oven. If the process of firing the molds also includes burning out the pattern material (plastic or holowax), a flue must be provided.

In one shop, where holowax was used as the pattern material, the melting out was first performed in a drier, followed by firing the molds in PN-15 ovens. A flue was mounted on the drier, and the process proceeded normally. On transfer of the molds from the drier to the oven and during the firing, especially at temperatures of 300-450°C, a violent liberation of holowax fumes took place, which penetrated into the shop. Forced ventilation through the ducts from the oven doors was unable to eliminate the gases, which even passed through the oven lining and the insolating powder. After this, a flue was installed in the PN-15 ovens. This flue was 100 mm in inside diameter and provided with an outside layer of heat-insulating material. This measure fully justified itself. All the gas now was discharged through the flue. A damper in the flue was closed as soon as the temperature in the oven reached 600°C. The installation of this flue made it possible to have all

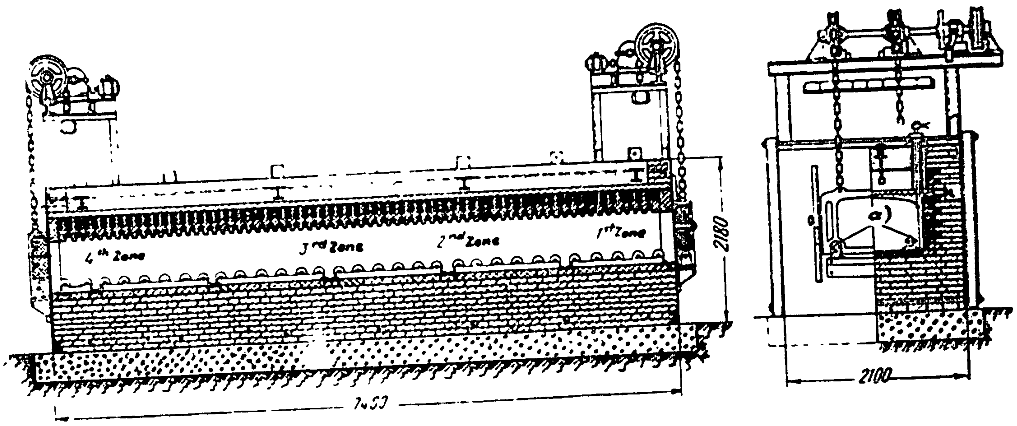

Fig.35 - Continuous Electric Oven of Pusher Type

a) Roller Conveyor.

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burnout of the pattern material take place in the oven (by-passing the drier). The increased draft produced by the flue did not extend the firing cycle.

Ventilating systems are often clogged by waste pattern materials, and must be regularly cleaned by disassembling the pipes and even the fan. The flues do not require cleaning, since the deposits of pattern material are completely consumed by the heat in the oven.

Drying and firing of the molds are very important operations in precision casting. They must be carefully controlled, and no interference with the operating condition must be permitted. The drier and ovens must be provided with potentiometers, with automatic recording of the drying and firing conditions on the tape of a recorder. Not less than twice during each shift, the instrument readings must be verified with a control thermocouple.

VIII. ELECTRIC STEEL SMELTING FURNACES IN FOUNDRY SHOPS

In the majority of foundry departments of modern machine building plants, arc and high-frequency furnaces are used for smelting steel.

A description of a few types of electric steel-melting furnaces in widest use for making finished alloys and remelting them for pouring the molds in precision casting is given below.

Electric Arc Furnaces

According to the character of their operation, the arc furnaces used in precision casting are subdivided into furnaces with a dependent arc, in which the arc is formed between the electrodes and the metal itself, and furnaces with a free arc, in which the metal is melted by the heat of the arc passing between two electrodes at a certain distance from the metal.

Furnaces with Dependent Arc. Industrial furnaces of this type are designed for widely varying capacities, from 500 kg to tens of tons.

The furnace shell is made of boiler iron in the form of a welded frame of

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cylindrical or elliptical form. The shell has one or more charging ports and one discharging port with a tapping spout. A rotary device allows the furnace to be tilted at an angle of 40-60° toward the tapping and charging ports. The shell is lined with highly refractory brick. The inner cavity of the furnace, bounded by the lining, is the smelting space of the furnace (Fig.36).

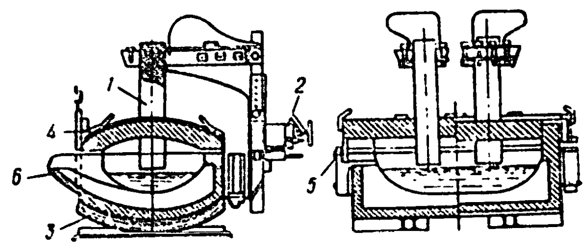

Fig.36 - Diagram of Electric Furnace with Dependent Arc

1 - Electrode; 2 - Mechanism for setting electrodes; 3 - Runner on which furnace is rotated; 4 - Slide gate; 5 - Charging port; 6 - Tapping spout

In some furnaces the vault is removable; in such arrangements, the furnace is charged after the vault has been removed. This presents a certain advantage in time for the charging and servicing of the furnaces, but the durability of the lining is somewhat impaired.

Crossbars installed on the furnace are used for guiding the carriers of the electrode holders, which move the electrodes downward as they are consumed. In furnaces of this type, the electrodes are usually arranged in vertical position, passing through cooled openings in the vault of the furnace which are called economizers.

Three-phase furnaces are most widely used. These use three vertically located graphite electrodes as the heat sources. Arc furnaces of this type receive their

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electric power from powerful three-phase transformers which supply the electrodes with currents of high intensity (tens of thousands of amperes) at a relatively low voltage (220-110 volts).

Table 5 gives the principal technical data of a few electric arc furnaces with dependent arc, produced in the USSR.

Furnaces with Tree Arc. These furnaces have found wide use for melting bronze, brass, alloy, and forged iron. They are also used for melting steels.

Table 5

Technical Data of Arc Electric Steel-Melting Furnaces

Furnace Type	Capacity, tons	Power*, kw	Type of Current	Electrode** Diameter, mm	Voltage, v	Electrode Adjustment	Duration of Heat, Hours
DST-0.5	0.5	400	Three-phase	100-150	190/110	Manual and Automatic	1.5
DST-1.5	1.5	900/400	Three-phase	125/225	200/116	Automatic	1.5
DST-3	3.0	1500/800	Three-phase	175/300	210/121	Automatic	1.75
DST-5	5.0	2250/1000	Three-phase	225/350	220/127	Automatic	1.75

* Numerator, in delta connection; denominator, in star connection.

** Numerator, graphite electrodes; denominator, carbon electrodes.

A furnace of this type consists of a cylindrical drum with horizontally located axis. Along the generatrices of the furnace, a charging port is cut, through which the molten metal is also tapped. The port is closed with a hinged, locking door. The faces of the drum are closed by bolted covers having ports for accomodating graphite electrodes. The shell and faces of the drum are made of boiler iron.

The drum is lined with special blocks of high-grade chamotte, with an inner lining of insulating brick. If chamotte blocks are unavailable, the furnace may be lined with ordinary chamotte brick if they are carefully dressed and fitted. The door is lined with molded chamotte.

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The furnace shell has two hoops (Fig.37) with a toothed surface; these are engaged by two pairs of rollers attached to the stand. By the aid of these rollers and a reversing electric motor, the furnace drum can be rotated through an angle of 30°C to 200°. The rotation of the furnace has several objects: The molten metal is more uniformly heated, the metal is better mixed, the furnace lining is cooled on rotation and is not as readily attacked by the metal.

In the face openings of the furnace, through special chamotte bushings, the graphite electrodes, located along the furnace axis, are inserted. The feeding of the electrodes as they burn away is regulated by a shaft governor. The voltage from a single-phase circuit is supplied to the electrodes over flexible cables. The electrode holders and the openings for the electrodes in the furnace faces are water-cooled.

The furnace is charged through the door. When the charge begins to melt and liquid metal is formed, the reversing electric motor is turned on and the furnace is rocked, at first through a low angle, and then, as all the metal melts, the rocking is increased to an angle of 200°.

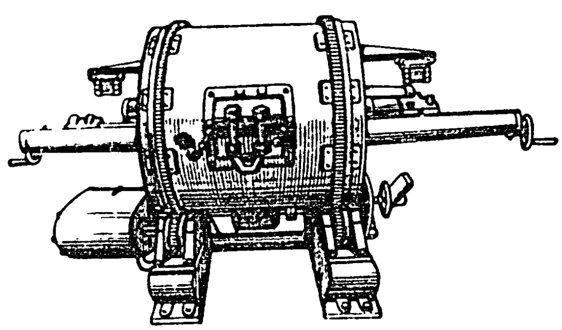

Fig.37 - Rocking Electric Arc Furnace

Table 6 gives data on the rocking electric furnaces.

Table 6

Rocking Electric Arc Furnaces

Furnace Capacity, tons	Voltage, v	Electrode Diameter, mm	Power, kv-amp
0.10	100	75	125
0.25	100	75	175
0.50	110	100	250
1.00	110	150	350

High-Frequency Furnaces

Of the high-frequency furnaces, the coreless furnaces with machine generator have proved satisfactory in steel-melting practice.

Setup of Installation. The coreless induction furnace is constructed as follows (Fig.38): An alternating electric current is fed to the furnace coil, known as inductor. This current, passing through the inducator, produces an alternating magnetic field, penetrating the furnace lining and the lumps of the metal charge in the crucible. The eddy currents, generated in the metal, heat the charge to the melting point. Originally, such furnaces were operated on high-frequency current (up to 100,000 cycles); later, it was found that they could be operated at relatively low frequencies (500-2500 cycles). Modern installations with machine generators operate at this frequency.

Furnaces with machine generators are assembled from the following basic units:

a) induction furnace (usually two furnaces in a set);

b) capacitor batteries

c) high-frequency generators;

d) exciter for generator (amplidyne);

e) electric motor for driving the generator;

f) electric installation, measuring, blocking, and starting apparatus.

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The furnace consists of a crucible, stamped of refractory material and placed within the inductor; the crucible is stamped from a specially designed conical pattern, which, after stamping, is extracted or melted out.

The inductor is a copper tube through which an alternating electric current is passed; the inductor is cooled by running water and is insulated from the side of the furnace by a special paste and sheets of dielectric material (micanite or asbestos).

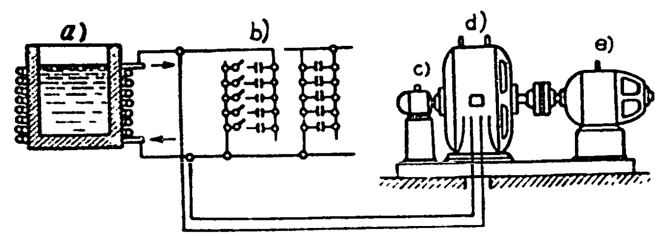

Fig.38 - Diagram of Induction System with Machine Generator

a - Induction Furnace; b - Capacitor; c - Exciter; d - Generator;

e - Motor

The battery of static capacitors permits considerable saving in generator power. It also permits regulation of the cos φ of the installation, within limits close to 1. In installations with generator machines operating at relatively low frequencies, flat capacitors of metal foil with a thin layer of paper (insulating material) with water-oil or oil cooling are used; at higher frequencies, mica, ceramics, or air are used as insulators for the capacitors.

The generator is used for producing a high-frequency current, induced in the winding located in the grooves of the stator; the stator also carries the exciter winding (pole winding). The rotor and stator have projections and recesses which produce a pulsation of the magnetic flux on rotation of the rotor.

The exciter is a direct-current machine for producing the excitation current in the rotating generator; the exciter feeds the pole windings of the stator of the generator.

The electric motor of the generator is an ordinary alternating-current motor of industrial frequency; its purpose is to drive the rotor of the generator and exciter.

Table 7 gives the technical data of the principal equipment for several types of high-frequency furnaces which are most widely used in industry.

Furnaces of Type PO-150, IV-60. The high-frequency installation consists of a set of the above equipment. In the foundry shop, the mounting to the pouring stage is usually done so that the furnaces themselves are on the stage, while all the electric equipment (generator and motor, capacitors, starting device, etc.) is in a specially equipped room. All controls of the installations are placed on a switchboard mounted on the wall, separating the generator from the melting areas.

The generator room must have proper foundations underneath the electric motor and generator, easy access for servicing all units, a water supply for cooling the capacitors, and a lifting device for use when the generator and electric motors are to be removed for overhauling and replacement. There must also be a satisfactory suction ventilation equipment with dust filters for cooling the operating units; dirt and dust are absolutely impermissible in the generator room, since they lead to trouble if they get into the high-speed machinery. The door of the generator room must be so blocked that entrance into the room is entirely safe. All wires from the units are placed in special conduits designed for accomodating the necessary cross sections of the cables and bus bars, which must be protected properly.

The dismountable equipment PO-150 and IV-60 comprises two furnaces in the set, of 150 and 70 kg capacity; however, only a single furnace of the unit can operate at one time. The second furnace is for standby service. The connection of either furnace is effected by means of a hinged knife-surtch, mounted in the generator room. The knife-switch can be switched only when the installation is entirely turned off.

Control funnels are mounted to the melting floor to supply water for cooling the inductors, contacts, and capacitor of batteries. The temperature of the outlet water must not exceed 40°C. In addition, the water flow must be continuous. If the waste water stops flowing from any pipe, this indicates clogging of the connection, or trouble. The system must then be turned off and the trouble corrected.

The IV-60 system differs from the PO-150 not only in power and productivity, but also by the fact that, in the former equipment, an attempt was made to build a single motor-generator unit. But this arrangement has its weak points; the bearings operate inefficiently on the generator side, the common shaft is not protected from axial displacement, the lubrication system does not operate properly, and oil from the bearings is hurled on the motor winding during operation.

It is to be hoped that these shortcomings will be eliminated by the "Elektrik" plant when it produces the next batch of machines, since the need for 60-kg furnaces for steel melting is very great, particularly in precision casting.

In the IV-60 installation, the furnaces can be mounted directly on the floor instead of on a platform since their height is relatively low. The furnaces are not equipped with a rotating mechanism; this is made up on the spot in the form of a handwheel with a reducing gear or is replaced by a hoist or telpher. The output of the IV-60 installation is 35-37 kg of steel per hour. The melting of 60 kg steel in a cold furnace takes 1 hour 35 min to 1 hour 45 min; in the hot furnace 60 kg of steel will melt in 1 hour 20 min.

The PO-150 installation, in view of the large size of the furnaces, is mounted on a special platform (Fig.39). The furnaces are provided with rotating mechanisms having a chain drive from a separate electric motor; the angle of maximum rotation of a furnace is 90°. The PO-150 furnace is not designed for direct pouring of precision-casting molds and is generally used for preparation of the alloy. Its output is 72-75 kg of steel per hour. The melting of 150 kg of steel in a cold furnace takes $2\frac{1}{4}$ to $2\frac{1}{2}$ hours; in the hot furnace, 150 kg of steel will melt in two hours.

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Table 7

Technical Data of Principal Equipment of High-Frequency Induction Furnaces with Generator Machine

a)	b)	c)							d)					
		e)	f)	g)	h) cos φ	i)	k)	l)	m)	n)	o)	p)	q)	r)
s)	150	185	380	91,5	0,87	3000	50	v)	150	0,88	1500	3000	2000	w)
t)	60	80	220 380	—	0,91	2950	50	•	49,5—57	0,87	330 - 380	2950	2500	•
u)	500	375	6000	—	—	1450	50	•	350	—	800	1350	1000	•

a) Type of installation; b) Furnace capacity (steel), kg; c) Driving electric motor; d) Frequency Generator; e) Power, kw; f) Voltage, v; g) Efficiency; h) cosφ; i) rpm; k) Frequency of feed current, cps; l) Type of current; m) Poser kw; n) Efficiency; o) Voltage, v; p) rpm; q) Frequency, cps; r) Type of current; s) PO-150; t) IB-60; u) AYaKS; v) Three-phase; w) Single phase

x)

y)	z)	aa)				bb)				
		cc)	dd)	ee)	ff)	gg)	hh)	ii)	jj)	kk) %
s)	150	0,65	110	3000	ll)	2316	12	1500	2000	0,4
t)	60	1,0	60	2850	•	—	0,75—1,5	600	2500	—
u)	500	2,5	110	2850	•	5750	115	1250	1000	—

x) Table continued; y) Type of installation; z) Furnace capacity (steel) kg; aa) Exciter for Generator; bb) Capacitor battery; cc) Power, kw; dd) Voltage, v; ee) rpm; ff) Type of current; gg) Total power, kvar; hh) Power of one bank, kvar; ii) Voltage, v; jj) Frequency, cps; kk) Loss, %; ll) Direct current

Lining of the IV-60 and PO-150 Furnaces. The first step in lining these furnaces is a proper insulation of the inductor. The inductor must be insulated to

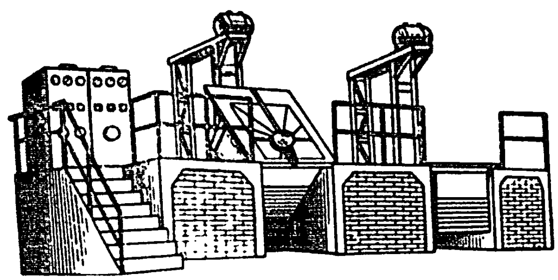

Fig.39 - General View of Melting Platform for Induction Furnaces with Machine Generator

prevent short-circuits between the windings and breakout of metal from the crucible. In case of such an accident, an uninsulated inductor might instantaneously catch fire and fail; overhauling of the inductor often requires complete disassembly of the furnace and prolonged stoppage of the installation. In addition, application of a smooth insulating layer to the inside of the inductor facilitates the work of packing the crucible.

Before insulating it, the inductor must be throughly cleaned and painted with two coats of enamel paint.

The composition of the mixture for insulating the inductor is as follows (in%):

Quartz sand, K 50/100	50
Quartz dust	15
Chamotte brick, shards (grains passing screen No.40)	6
Alumina cement (grades 300-500)	10
Waterglass (sp. gr. 1.25)	5
Water	14

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In view of the rapid setting of alumina cement, no large quantities of insulating mixture can be prepared in advance.

The dry ingredients are weighed in the above percentage ratio and are thoroughly mixed in a laboratory crusher for 10-15 min. The waterglass is then diluted with a measured quantity of water, poured into the dry mixture, and thoroughly mixed. The mixture should have the consistency of heavy cream.

The prepared mixture is immediately applied to the inductor from the inside, and is forced out between the turns of the inductor. The roughness of the layer is smoothed from the inside. The thickness of the insulating layer must not be less than 3-5 mm. After the inductor has been completely covered with the insulating layer, it is allowed to dry for 8-10 hours, after which it is further dried with an electric heater for 4-6 hours at a temperature of 100-120°C. The cracks in the paste formed after drying, must be filled with the same insulating composition from inside the inductor. The outer surface of the inductor need not be insulated, but the insulation of the spaces between the turns must be carefully checked. In order to protect the insulating layer when the lining is packed in, the insulated inductor must be covered with asbestos sheets from the inside*.

The furnace, with the inductor prepared in this manner, is now ready for lining.

The lining may be either acid or basic in composition and, accordingly, forms acid or basic slags on melting of the metal. Acid linings are based on silica (SiO_2) and are made of a special dinas brick, or are made by packing quartzites or quartz sands. Basic linings consist of magnesite, dolomite, or chromomagnesite, and are either made of brick or are packed from the corresponding powdered materials. The

*Another formulation for insulating the inductor is in use, with ethyl silicate as the binder. However, this mixture is more expensive and yields no noticeable advantages over that described above.

lining composition largely determines the subsequent process of melting the metal: acid or basic slags are used, the individual elements (such as silicon) are differently proportioned, and the process of deoxidation of the metal is conducted differently.

Basic Lining. Chromomagnesite is widely used for basic lining.

The small dimensions of the furnace and the very thin lining layer do not allow high-frequency induction furnaces to be lined with ordinary brick; such furnaces are lined by packing, using a sweep, with a special lining slurry, prepared in the following manner: Chromomagnesite brick (shards) is crushed in a special crusher and screened. For the lining slurry, the chromomagnesite granules are taken in a strictly determined ratio with respect to grain size, as follows:

Grain size No. 12	10%
Grain size No. 30	30%
Grain size No. 70 and finer	60%

To this, 6% of fire clay, dried, crushed in a crusher or on crushing rollers, and graded through screens No.30, is added. The material is thoroughly mixed and moistened with an aqueous solution of boric acid (12 gm of boric acid per liter of water). For moistening 12 kg of the prepared lining mixture, 1 liter of boric acid solution is needed.

The moist mixture is thoroughly mixed and covered with wet burlap. Letting the mixture stand in this state for 3-4 hours is recommended. The mixture, "swells" and acquires more plastic properties, after which it is ready for lining the furnace. In moistening the mixture, particular care must be taken to avoid unmixed wet lumps and poorly wetted places.

Special sweeps are used for lining high-frequency induction furnaces. The sweep is made sharp, with an insignificant lightening, for lining furnaces of small capacity; for the 60-kg furnace of the type IV-60, a collapsible sweep of three wedges is used; for large-capacity furnaces (200 and 500 kg), a welded sweep is prepared from tin sheets, filled with iron scrap to weight it when the lining is packed. The inductor, first insulated, is then packed on the side walls with asbestos board. Next, the sole of the furnace is packed, usually to the second turn of the inductor. The lining slurry is spread in an even layer 30-40 mm thick and is rammed in tightly with metal rammers. After packing the furnace vault, the sweep is placed in position. In the upper part of the inductor, it is fixed by three wooden wedges to prevent it from shifting. The space between the inductor and the sweep lining is filled with slurry, also in 30-50 mm thick layers, and is rammed in a circle with rammers. After ramming the next layer, before spreading a new portion of the slurry, it is recommended to scratch the rammed layer slightly with a crow-bar, so as to prevent (to a certain extent) the lining from peeling. The durability of the lining during the melting process largely depends on the care with which the lining slurry is prepared and on the density with which it is packed.

The lining, once started, should not be interrupted until finished, since any interruption in the ramming leads to peeling which, during operation, may be the beginning of a crack in the lining.

The lined furnace must be thoroughly dried. After 4 to 6 hrs, the sweep may be removed from the furnace (if it is sharpened or built-up). In a welded sweep, which cannot be removed from the furnace, a large number of holes are usually drilled to facilitate drying. The natural drying of the furnace is continued for not less than 24 hrs; after this, the electric heating element is installed in the furnace, and the furnace is dried for another 12-24 hrs, depending on the volume of the lining. The dried furnace can then be charged with metal for the first flushing heat.

The first heat in a newly lined furnace must be conducted as quiescently as possible, using the lowest power. Usually, the first heat proceeds two or three times more slowly than the regular heats. The metal from the first heat cannot be used for casting parts, since it is strongly saturated with the gases liberated by

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the new lining. The first metal should be superheated in the furnace as much as possible and rapidly poured out. This keeps the lining clean, so that the crucible can be checked thoroughly in the hot state, "in the light", when the smallest cracks in the lining become visible. Iron is recommended for use in the first flushing heat, and should be brought to a temperature of 1450-1500°C.

Acid Lining. The lining of a furnace with acid material is performed in exactly the same way. The only difference is that the chromomagnesite is replaced by quartzite. The process of packing the furnace, natural drying, drying with warm-up, and the first melt are performed in the same way as in lining with basic material.

In some plants, the furnaces are dried by passing current from the installation through a welded sweep. This method of drying has not proved satisfactory and the frequent switching on and off of the power plant will always cause damage; therefore, this method of drying should not be used.

Repair and Maintenance of the Lining. The part failing most frequently is the so-called gate of induction furnaces. This is the upper part of the lining, running from the last turn of the conductor to the top of the furnace with a certain upward flare, as well as the lining of the tapping spout of the furnace. The fact that these parts fail first is explained by the corrosive action of the slag during melting, and by the deposits formed on the tapping spout during tapping.

The defective parts of the lining should be cleaned of slag and filled in with a lightly rammed lining slurry, having a somewhat higher clay content (up to 10-12%). Complete replacement of the furnace gate portion is permissible. The lining repair must be done carefully, avoiding all cracks.

After each heat, the lining must be inspected by the foreman, who decides whether it is suitable for further use.

IX. MELTING OF METAL AND POURING MOLDS

Brief Data on Alloys used in Precision Casting

Almost all known metals and alloys can be cast into parts of the most intricate

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form by the method of precision casting. However, nonferrous metals and alloys whose melting point does not exceed 1100°C are cast relatively seldom by this method, since high finish and very exact castings with these alloys can be obtained by a shorter and less expensive method, namely pressure casting into metal molds or chill casting. Exceptions are certain complicated parts of bronze, which are cast by precision casting in order to reduce the tolerances as much as possible.

The situation is different in casting high-alloy steels and other alloys, mostly of high hot-strength and high fire resistance, at pouring temperatures of 1500-1700°C. Here pressure casting into metal molds is not applicable, while chills wear out rapidly and become unfit for casting a large number of parts. It is extremely difficult to machine most fire-resistant alloys of high hot-strength. This, as well as the need for reducing the metal losses, make precision casting of complex parts from fire-resistant and high-melting alloys sometimes the only useful method of production. Rigid specifications, which are dictated by the service conditions of the parts, are usually established for fire-resistant alloys of high hot-strength.

The most important of these conditions is high fire resistance. The property of a metal of resisting the formation of oxide skins at high temperatures is called fire resistance. This is determined by the loss or gain in weight of a selected test specimen in unit time per unit area, a definite temperature. It is customary to consider that steel is highly fire-resistant if the gain in weight due to skin formation does not exceed 1.0 g/m^2/hour. The higher the fire resistance of parts used at high temperatures, the less will be the danger of pitting of such a part and the smaller the amount of skin formed, the longer will the original cross section of the walls be preserved and, consequently, the higher will be the mechanical strength of the part.

The hot-strength is judged by the mechanical properties of a metal at high temperatures. The characteristic of hot-strength is the time in hours before a specimen of metal will yield when subjected to tension at a given test temperature and load.

Below, brief characteristics (Bibl.15,16,17) of the principal physico-chemical and technological properties of typical steels and of iron, nickel and cobalt alloys, cast by precision casting, are given.

Chrome-Nickel Fire-Resistant Steel Kh23N18 (EI-417). This steel is used for casting nozzle rings for gas turbines. Pouring temperature 1500-1550°C (by optical pyrometer, without corrections). Linear shrinkage 2-2.5%. After casting, heat treatment is recommended: hardening at 1100°C in air. The chemical and mechanical properties are given in Tables 8,9, and 10.

Table 8

Chemical Composition of Kh23N18 Steel (in %)

Fe	Cr	Ni	C	Not Over			
				Si	Mn	P	S
Residual	22-25	17-20	0.18	1.0	1.50	0.03	0.035

Table 9

Mechanical Properties of Kh23N18 Steel (in Precision Cast Specimens)

Specimen No.	State	At Room Temperature			At Temperature of 800°C		
		Tensile Strength, kg/mm²	Elongation, %	Necking, %	Tensile Strength, kg/mm²	Elongation, %	Necking, %
1	Cast	53.1	30.8	35.2	22.6	17.6	18.0
2	Cast	52.0	33.3	36.8	16.6	19.0	16.8
3	Cast	51.8	31.7	25.0	21.5	17.8	19.6
4	Cast and Heat-treated	50.0	27.4	54.4	20.5	19.2	20.7
5	Cast and Heat-treated	52.3	30.5	40.0	22.6	21.0	17.2
6	Cast and Heat-treated	51.0	28.8	38.8	20.5	18.7	17.2

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Table 10

Hot-Strength of Kh23N18 Steel

State	Test Temp. in °C	Stress, kg/mm²	Ultimate Strength, hrs	Remarks
Cast	700	10	116	Specimen loaded at bottom to 13 kg/mm²
		13	19	Specimen loaded at bottom to 15 kg/mm²
		15	107	Specimen removed
			Total 242	

<u>KhN80T Nickel-Chrome-Titanium Heat-Resistant Alloy</u>. This alloy is used for casting gas-turbine blades. The casting properties of the alloy are poor. The pouring temperature for molds in casting intricate ofenwork parts is 1500-1560°C. Very strong oxidation during melting. The alloy acquires its maximum hot strength after hardening at 1050-1080°C (quenching in water) and aging at 700°C for 16 hrs.

Tables 11,12, and 13 give the chemical composition and mechanical properties of the alloy.

Table 11

Chemical Composition of KhN80T Alloy (in %)

Ni	Cr	Ti	Not Over							
			C	Si	Mn	Al	S	P	Cu	Fe
Residual	19-22	2-2.8	0.08	1.0	0.6	0.8	0.03	0.03	0.5	4.0

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Table 12

Mechanical Properties of KhN80T Alloy

State of Material	At Room Temperature			At 800°C		
	Tensile Strength, kg/mm²	Elongation, %	Necking, %	Tensile Strength, kg/mm²	Elongation, %	Necking, %
Hardened	75	40	45	-	-	-
Hardened and Aged	105	20	30	40	7	12

Table 13

Hot Strength of KhN80T Alloy

Test Temp, °C	Stress, kg/mm²	Ultimate Strength, hrs	Elongation, %	Necking, %
800	15	20	1.7	1.3
800	10	100	1.5	1.0

<u>Vitallium-Type Casting Alloy</u> (Tables 14,15 and 16). This alloy is used for casting gas-turbine blades and guides for nozzle-ring vanes. The pouring temperature for the molds is 1520-1560°C. The parts are not subjected to heat treatment.

Table 14

Chemical Composition of Vitallium Type Casting Alloy, (in %)

Co	Cr	Mo	Ni	C	Not Over				
					Mn	Si	Pe	P	S
Residual	25-28.5	4.5-5.5	3.0-3.75	0.2-0.3	0.6	0.5	3.0	0.04	0.04

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Table 15

Mechanical Properties of Vitallium-Type Casting Alloy

State of Material	At Room Temperature			At 800°C		
	Tensile Strength, kg/mm²	Elongation, %	Necking, %	Tensile Strength, kg/mm²	Elongation, %	Necking, %
Cast	70	8	10	40	10	40

Table 16

Hot-Strength of Vitallium Type Alloy

Test Temp, °C	Stress, kg/mm²	Ultimate Strength, hrs	Elongation, %	Necking, %
816	15.4	100	6.8	19.7

In addition to the above alloys, other special steels and alloys are used in precision casting (for example, the steel 21-11-2.5 discussed below), as well as bronzes.

Preparation of Steel from Raw Materials

In series production by precision casting, it is seldom necessary to produce steel from the raw materials. The casting shops are usually supplied with the finished steels and alloys by the metallurgical plants. Such deliveries meet special specifications and are accompanied by certificates giving the chemical composition of the steel or alloy and the results of tests of the properties prescribed by the specifications.

If, because of certain processing conditions, steel must be made at the shop, a furnace of the largest possible capacity (1000, 500, 200 kg) should be used, since a large number of small batches of the original alloy with varying chemical composition complicates the processing and results in a great variety of chemical compositions of the castings.

The purity and grade of the raw materials is particularly important when the alloy is prepared at the shop. Only materials corresponding to certain definite grades, defined by technology and accompanied by certificates, should be put into production. Each new batch should be tested in chemical or spectroscopic laboratories for harmful impurities like sulfur and phosphorus, as well as for elements which vary in their percentage content during the melting process more than other elements, due to irregular oxidation loss or due to the composition of the lining or of the slag. This is made necessary by the fact that a low-grade batch of any material, in addition to causing spoilage of the parts cast from this batch, will also, to a large extent, ruin the reclaimed metal that goes into the charge in the form of gates and risers, and will exercise an unfavorable influence on the quality of the castings produced.

Basic Requirements for Steel. Parts cast by precision casting must meet the assigned chemical composition; therefore, the content of individual elements in steel is often held within very narrow limits.

The chemical composition of the steel is determined primarily by the composition of the charge, which may consist either of pure metals or of their alloys. For alloys on a ferrous base, additives of elements like silicon, manganese, tungsten, molybdenum, vanadium, titanium, and others, are often introduced in the form of ferrous alloys (cf.Tables 20, 21, etc.).

The smaller the amount of harmful impurities in the individual constituents of the charge, the more carefully the charge has been selected, and the more accurately it has been calculated for all elements entering into the alloy, the more exactly will the chemical composition of the alloy produced be maintained.

The chemical composition of an alloy depends largely on the technology of melting. The order of loading the charge, the temperature conditions of the melting, the duration of the melting and pouring, all substantially affect the fluctuation of the chemical composition of the alloy. In protracted heats, the oxidation loss of the individual elements is increased, which changes the chemical composition of the alloy. The smelting furnaces themselves also influence the chemical composition. For example, in working with an electric arc, considerably less carbon should be included in the charge than when smelting an alloy in high-frequency furnaces, since the graphite electrodes used in arc furnaces somewhat saturate the alloy with carbon, while when an alloy is smelted in high-frequency furnaces, the carbon is partially lost by oxidation (volatilized in the form of CO and CO_2). Alloys in which the silicon content is held within narrow limits must not be smelted in furnaces with an acid lining of quartzites, since this will increase the silicon content in the alloy and the silicon will "burn in" at the expense of the lining. The type of flux exerts a considerable influence on the chemical composition. Covering the surface of the molten metal in the form of slag, the flux reacts in a certain manner and modifies the chemical composition of the alloy.

The purity of the pigs of cast alloys is of great importance for precision casting, which explains the rigid specifications for precision castings of vital parts. Pigs contaminated by inclusions of disintegrated furnace or ladle lining, or poorly removed slag, cannot be accepted for the production of precision castings. For this reason, the lining of the smelting furnace must be kept in good condition; the liquid slag must be removed before tapping the furnace, first thickening it with a special additive, or must be brought into the solid state in the form of a crust, tapping the metal from under the crust; the slag is easily trapped by special stoppers and teakettle ladles.

In melting, under the influence of high temperature, the tendency of an alloy to oxidize is greatly increased. Oxide films in the metal form weak and friable spots, that interfere with the continuity of the material. This impairs the mechanical properties of the castings. The oxide films must be controlled by proper selec-

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tion of the flux and careful conduct of the process of melting and pouring. Melting and pouring of metal under a protective atmosphere of inert gases has recently been widely applied in foundry production. To reduce the films, the pouring should be done as rapidly as possible, which is accomplished by the use of stopper ladles. Specially constructed warming risers on the ingates have proved satisfactory in the control of oxide films.

To remove the iron oxide (FeO) dissolved in the liquid steel, which lowers the purity of the pig, special materials known as antioxidants are introduced into the liquid bath, shortly before pouring.

The antioxidant most widely used in steel smelting is manganese; this is usually introduced into the molten steel together with silica, since manganous oxide is slightly soluble in steel. Aluminum energetically deoxidizes steel; the alumina (Al_2O_3, a very refractory product) which is formed on deoxidation does not dissolve in the steel but passes completely into the slag. At present, compound antioxidants are widely used. They contain two or three reducing elements (silico-calcium, etc.); and are active antioxidants, forming compounds insoluble in steel, which pass completely into the slag.

Attention should be paid to rational tapping of steel smelted for subsequent remelting and casting into parts. The alloy must be tapped into a mold convenient for later remelting. Special cast-iron ingot molds are used for this purpose. The alloy cast into such ingot molds is then relatively easily divided into lumps ("pigs") which are convenient for subsequent remelting. Sometimes shills and half-chills (a type of small ingot molds) are used for tapping the alloy. The alloy can also be cast into sand molds, where the metal is poured into very small pigs, convenient for subsequent remelting of small portions of alloy. A sufficient number of molds must be available so as not to delay the tapping (which favors oxidation of the alloy and its solidification in the furnace), which should be performed in the shortest possible time.

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Below, examples of the smelting of steel in arc and high-frequency furnaces with acid and basic lining are presented.

Smelting of 21-11-2.5 Steel. As an example of the fabrication of steel in an acid arc furnace of 1.5 tons capacity, we present a heat of 21-11-2.5 steel.

Chemical Composition and Starting Materials. The chemical composition of the smelted steel must meet the specifications given in Table 17.

Table 17

Chemical Composition of 21-11-2.5 Steel

Composition of Steel	Chemical Composition in %				
	Fe	C	Si	Mn	Cr
By Specifications	Residual	0.10-0.25	0.7-1.5	0.6-1.2	20.0-22.0
Composition for Figuring Charge	Residual	0.15	0.92	0.84	21.0

Continued

Composition of Steel	Chemical Composition in %						
				Impurities, not Over			
	Ni	[illegible]	Ti	S	P	Mo	V
By Specifications	11.0-12.5	2.4-3.0	0.05-0.20	0.040	0.045	0.25	0.20
Composition for Figuring Charge	11.5	2.55	0.10	0.026	0.038	-	-

The steel is smelted in an acid electric arc furnace; up to 30% of degreased and well-dried shavings are added to the charge and up to 30% of lump scrap 21-11-2.5 steel. The remainder of the charge consists of fresh materials of the chemical composition given in Tables 18-27.

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Table 18

Low-Carbon Steel (by GOST 3836-47)

Chemical Composition in %, not Over

C	Mn	Si	S	P	Cu
0.040	0.20	0.20	0.03	0.025	0.15

Note. Copper content over 0.15% up to 0.38% is not considered a cause for rejection of the steel.

Table 19

Nickel, by GOST 849-49

Chemical Composition in %							
Grade	Ni and Co Together Not Less Than	Ni			Impurities, not Over		
			Fe	Si	C	S	Cu
H2	98.9	98.5	0.25	0.30	0.10	0.03	0.15

Table 20

Ferrochromium (by GOST 4757-49)

Group of Ferrochromium	Grade Designation	Cr	C	Chemical Composition in %			
				P	S	Al	Si
		Not Less than		Not Over			
Carbon-Free	Khr000	65	0.10	0.04	0.04	-	1.5

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Table 21

Ferrotungsten (by GOST 4758-49)

	Chemical Composition in %								
Grade	W	Mn	Cu	S	P	C	Si	As	Sn
	Not Less than					Not Over			
V1	70.0	0.20	0.25	0.08	0.05	0.50	0.40	0.05	0.10

Table 22

Ferrotitanium (by GOST 4761-49)

	Chemical Composition in %						
Grade	Ti	C	Si	P	S	Al	Cu
	Not Less than				Not Over		
Ti1	18.0	0.20	3.5	0.05	0.05	5.0	[illegible]

Table 23

Metallic Manganese (by GOST [illegible])

	Chemical Composition in %								
Grade	Mn	Si	P	Al	Fe	Cu	C	S	Total Impurities
	Not Less than				Not Over				
Mp1	95.0	0.8	0.05	-	2.5	-	0.10	-	5.0

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Table 24

Ferrosilicon (by GOST 1415-49)

			Chemical Composition in %		
Grade	Si	Mn	Cr	P	S
			Not Over		
Ci75	72-78	0.70	0.50	0.05	0.04

Table 25

Ferromanganese (by GOST 4755-49)

				Chemical Composition in %		
Group	Grade	Mn	C	Si	P	S
		Not Less than		Not Over		
Medium-Carbon	Mi1	80.0	1.00	2.0	0.33	0.03
	Mi2	80.0	1.50	2.5	0.30	0.03

Table 26

Silicocalcium (by GOST 4762-49)

				Chemical Composition in %	
Grade	Ca	Ca+Si	Al	S	P
	Not Less than			Not Over	
KaSil	28.0	90.0	2.50	0.04	0.05

Table 27

21-11-2.5 Steel Scrap

					Calculated Chemical Composition in %						
Form of Scrap	C	Si	Mn	Cr	Ni	W	Mo	S	P	V	Ti
Lump Scrap or Shavings	0.17	1.0	0.80	21.3	11.0	2.3	0.10	0.02	0.03	-	-

Note. In figuring a charge, the necessary quantity of titanium will be determined without allowing for it in the 21-11-2.5 steel scrap.

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Figuring the Charge. In figuring the composition of a charge, the coefficients of incorporation of the elements in the heat of steel (Table 28) must be taken into consideration.

Table 28

Coefficients of Incorporation of Elements

Element	Si	C	Cr	Ni	W	Mn	Ti	S	P
Coefficient of Incorporation	1.0	1.0	0.90	1.0	0.95	0.55	0.4	1.0	1.0

The percentage content of individual components in the charge (a) is determined by the formula

$$a = \frac{100H - M_k c}{KC},$$

where H = calculated percentage compound of the element in the charge;

M = percentage content of lump scrap and shavings of 21-11-2.5 steel;

c = percentage content of element in 21-11-2.5 steel scrap and shavings;

K = percentage content of element in ferrous alloy;

C = coefficient of incorporation of element (by Table 28).

Then, the content of ferrosilicon in the charge will be

$$a_1 = \frac{100 \cdot 0{,}92 - 60 \cdot 1{,}0 \cdot 1{,}0}{75 \cdot 1{,}0} = 0{,}42\%.$$

in figuring the charge, this will amount to

$$\frac{1500 \cdot 0{,}42}{100} = 6{,}3 \text{ kg}$$

The content of manganese in the charge will be

$$a_2 = \frac{100 \cdot 0{,}84 - 60 \cdot 0{,}8 \cdot 0{,}55}{95 \cdot 0{,}55} = 1{,}09\% \quad \text{or} \quad 16{,}35 \text{ kg}$$

The content of ferrochromium in the charge will be

$$a_3 = \frac{100 \cdot 21{,}0 - 60 \cdot 21{,}3 \cdot 0{,}9}{65 \cdot 0{,}9} = 16{,}2\%, \quad \text{or} \quad 243{,}0 \text{ kg}.$$

The content of nickel in the charge will be

$$a_4 = \frac{100 \cdot 11,5 - 60 \cdot 11,0 \cdot 1,0}{98,5 \cdot 1,0} = 4,974\%, \text{ or } 74,61 \text{ кг}.$$

The content of ferrotungsten in the charge will be

$$a_5 = \frac{100 \cdot 2,55 - 60 \cdot 2,3 \cdot 0,95}{70 \cdot 0,95} = 1,86\%, \text{ or } 27,9 \text{ кг}.$$

The content of ferrotitanium in the charge will be

$$a_6 = \frac{100 \cdot 0,1}{18 \cdot 0,4} = 1,39\%, \text{ or } 20,85 \text{ кг}$$

(no allowance is made for the titanium content of the scrap).

The content of 21-11-2.5 steel scrap in the charge will be

$$a_7 = 60\% \text{ or } 900 \text{ kg}$$

The required quantity of low-carbon steel will be found from the difference between 100% and the sum of the calculated components:

$$a_8 = 100 - 85.934 = 14.066\%, \text{ or } 210.99 \text{ kg}.$$

Since charcoal is introduced into the liquid bath during the deoxidation, the process of which is determined technologically, no calculation is performed for the carbon content.

Let us check the calculated charge for one of the harmful elements, for instance, for sulfur, which is contained in all of the charge components. The following amounts of sulfur will be introduced:

With the ferrosilicon, $\frac{6.3 \times 0.04}{100} = 0.002$ kg;

With the ferrochromium, $\frac{243.0 \times 0.04}{100} = 0.097$ kg;

With the nickel, $\frac{74.61 \times 0.03}{100} = 0.022$ kg;

With the ferrotungsten, $\frac{27.9 \times 0.08}{100} = 0.022$ kg;

With the ferrotitanium, $\frac{20.85 \times 0.05}{100} = 0.010$ kg;

With the iron, $\frac{210.99 \times 0.03}{100} = 0.063$ kg;

With the steel scrap, $\frac{900 \times 0.02}{100} = 0.180$ kg.

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In all, 0.396 kg of sulfur will be introduced with the charge; its percentage content in the charge will be

$$\frac{0.396 \times 100}{1500} = 0.026\%$$

which corresponds to the specifications.

The results of the determination of the percentage composition of the charge and the weight of the individual components of the heat is entered in the process chart of the heat (the charge sheet).

Preparing the Furnace for Smelting. For preparing the floor and sloping sides of the furnace, a repair lining slurry of one of the following compositions must be mixed on crusher rolls:

a)	Lyubereka sand	70%
	Tambov earth	22%
	Technical molasses	8%

or

b)	Lyubereka sand	99%
	Boric acid	1%

The mixing time for the repair slurry is 15-20 min.

After tapping a regular heat, the floor and sides of the furnace must be cleaned of slag and deposits while hot, and must be patched wherever necessary with the repair slurry by means of a special spade (repair shovel). The door is closed after the repair and 10 to 15 min time is allowed for the slurry to cement itself to the sole. Then clean and repair the tapping spout of the furnace, replacing the bricks if necessary.

Next, place the electrodes in such a way that they reach the entire melt without building up. Before charging, lift the electrodes to the upper position.

Before charging the furnace, three or four shovels of freshly burned lime must be thrown on the sole to improve the conditions of slag formation.

The weighed-out materials are charged in the following order: 30-40% of shav-

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ings are sprinkled in an even layer on the sole of the furnace, after which the largest lumps of the charge, remelt, and raw materials (except for the metallic manganese and ferrotitanium) and all of the fines, together with the remaining shavings, are thrown in. The lumps of ferrochromium are arranged along the slopes of the sole. Attention should be paid to the density of packing of the charge, since a loose charge hinders the burning of the arc and may cause breakage of the graphite electrodes and saturation of the metal with carbon.

Melting and Refining of the Metal. The charge furnace is started up for the melting. In order to start the furnace, the choke coils must be turned on, the transformer switched to delta connection, and the oil valve and automatic electrode feed turned on. After stable arcs are formed, the current intensity is adjusted. It must be in the range from 2700 to 3500 amp. As the liquid metal is formed on the electrodes, small amounts of the slag mixture are fed to the liquid bath. This mixture consists of two thirds of quartz sand and one third of freshly burned lime (parts by volume).

After the metal is completely melted, 5 kg of ferromanganese, brand Mn1 or Mn2, is fed into the furnace, after which the metal must be heated up, the bath carefully stirred, and a sample taken. A sample, in the form of a 20 x 20 x 50 mm bar, is sent to the rapid analysis room for determining the carbon, silicon, manganese, chromium, nickel tungsten, and titanium content.

All the slag is next pumped off, and 3 kg of finely ground silico-calcium is placed on the surface of the metal. New slag is added and diffusion reduction is performed. Before the reduction, the transformer must be switched over to star connection and the current strength adjusted to not over 1000 amp.

The diffusion deoxidation is performed by a mixture of the following composition:

Ground silico-calcium	6 kg
75% ground ferrosilicon	6 kg

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Ground charcoal (dry)	6 kg
Quartz sand (dry)	15-20 kg
Freshly burned line	9-12 kg

The mixture is first mixed thoroughly and then fed into the furnace on top of the slag in several portions. The metal and the slag, before charging of each portion of the mixture, is likewise thoroughly mixed. No local overheating of the slags should be permitted, since this causes a sharp reduction of the silica (formation of white smoke and flakes). In addition to thorough mixing, the furnace must be turned off for a few minutes, if necessary, to avoid reduction of the silica.

After the report is received from the rapid analysis room, the chemical composition of the metal is, if necessary, corrected. It is then heated to 1570-1600°C, while measuring the temperature with an optical pyrometer. From the bath, heated to this temperature, a sample is taken with a dipper and a test bar is poured. This test bar must have a concave meniscus, and the metal must harden without liberating gas. The metal sample is taken before addition of the ferrotitanium and metallic manganese.

The metal heated to the assigned temperature is mixed with the calculated amount of ferrotitanium, followed in 2-3 min by an addition of metallic manganese. The metal is maintained (for 5 to 6 min) under current, after which it is thoroughly mixed and the temperature is again checked.

<u>Tapping the Metal from the Furnace</u>. The finished metal is tapped into a ladle for subsequent pouring. The ladle must have a lining in good order, must be cleaned from deposits, and heated to a cherry red color. The ladle is heated in an oil furnace by means of a nozzle. No soot from the oil is allowed on the ladle; if contaminated, the ladle must be reheated by a blast with a smokeless flame.

For tapping the metal from the furnace, the tapping hole must be cleaned of sand and the sand removed; the ladle is then placed under the tapping spout of the furnace, the furnace is turned off, and the tapping spout is scavenged with compres-

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sed air. Then, by knocking with a long pick of 30-35 mm diameter, the tapping hole must be broken through and separated. The furnace is then rapidly tilted to retain the slag in the furnace and fill the ladle with metal. The metal is poured in accordance with the procedure for pouring established in the shop.

After tapping all the metal, the furnace must be cleaned of slag and prepared for the next heat.

If the metal is being poured in several portions, the metal remaining in the furnace must be corrected after every pouring for the manganese and titanium content by adding, if necessary, ferrotitanium and manganese.

In pouring the metal, its temperature at the pouring spout must be within the range of 1570-1600°C, as checked on the optical pyrometer.

It is compulsory to perform the operation of pouring the metal in the presence of the foreman and according to his instructions.

Smelting of Kh23N18 Steel. This steel is smelted in high-frequency PC-15C induction furnaces of 200 kg capacity, with a chromomagnesite (basic) lining.

Chemical Composition of Steel and Calculation of Charge. The chemical composition of the steel must meet the special specifications (presented in Table 29). Up to 70% of lump Kh23N18 scrap steel is introduced, with the rest being fresh material. For the smelting of steel, soft iron, ferrochromium, nickel, ferrosilicon, manganese, and other materials, having the chemical composition indicated in Table 18-26, are used. Low-carbon steel (St.10-St.25) may be used instead of soft iron.

The composition of the charge is figured for all elements (allowing for the coefficients of incorporation from Table 28) in a manner similar to the above-given calculation for 21-11-2.5 steel. The results of the determination of the percentage composition of the charge and the weight of the individual components of the steel are entered in the charge sheet.

Preparing the Furnace for the Heat. After tapping a regular heat, the crucible of the furnace, in the hot state, is cleaned of slag and is checked for the absence

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Table 29

Chemical Composition for Calculating the Charge of Kh23N18

Composition of Steel	Chemical Composition in %							
				Not Over				
	Fe	Cr	Ni	C	Si	Mn	P	S
By Specifications	Residual	22-25	17-20	0.18	1.0	1.5	0.03	0.035
Composition for Calculation of Charge	Residual	23.5	18.5	0.15	0.8	1.0	0.025	0.028

of cracks in the lining and for deeply corroded places. The defective places in the lining are filled with repair lining slurry. If there is a defect in the lining, the foreman decides in every case whether it is suitable for further operation, and whether melting is possible.

The weighed materials are packed as tightly as possible into the crucible. The individual lumps of the charge must not be larger than 150 mm in diameter. The nickel and ferrochromium are placed at the bottom of the crucible, followed by the remelt of Kh23N18 steel. Before the melting, a flux of the following composition must be prepared:

Unslaked freshly burned lime	80%
Metallurgical magnesite	15%
Fluorspar	5%

The lime is usually fired in lumps at a temperature of 800-900°C for 4-5 hrs. All ingredients are crushed and passed through a No.30 screen, and are then mixed in a pebble mill. The flux must be stored in a dry place in a closed container. In all, 4-5 kg flux are used to a heat of 200 kg.

Melting and Refining the Metal. Smelting of the charge is done at full power. As soon as liquid metal has formed, the slag is produced by sprinkling the first portion of the flux into the furnace.

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Since, because of the small capacity of the crucible, it is not always possible to charge all of the weighed charge into the furnace, as the metal melts and the charge settles, the remaining part of the weighed portion must be added, gradually settling the charge with a bar. The charge to be added must be preheated to prevent penetration of moisture, which may lead to an ejection of liquid metal from the furnace. When "bridges" are formed (hanging of the charge in the furnace) they must be removed ("settled") by a bar, without sharp impacts, loosening the hanging metal lumps by lifting them upward.

After melting the entire charge, the metal is carefully mixed by means of the bar, and its temperature is increased to 1500-1530°C, as indicated by the optical pyrometer. All the slag is then removed, and manganese is added to the metal; if necessary, finely ground powder of graphite electrodes is added. The metal is mixed and the slag is again removed. The temperature of the metal is then raised to 1520-1550°C, as read from the optical pyrometer.

After again removing the slag, ferrosilicon is introduced into the bath. The metal is kept under current and under a new portion of flux for 5-6 min; a test bar is then poured. If its crystallization is satisfactory and "growth" is absent, the pouring can be started.

<u>Tapping Metal from the Furnace</u>. As in the previous example of smelting in an arc furnace, the ladle must be carefully prepared and heated to a cherry-red color. In smelting an alloy in a high-frequency furnace, the metal is usually not subjected to analysis in the spot-test laboratory; however, for particularly vital castings, an analysis must be made for chromium, nickel, carbon, silicon, and manganese.

The finished metal is tapped through the pouring spout into the ladle by tilting the furnace. The furnace must first be turned off (in the presence of the foreman or the crew chief and under their supervision).

After all the metal has been tapped, the furnace, in the tilted position, is cleaned of slag while hot and is prepared for the next regular heat.

The alloy smelted in large-capacity furnaces is usually poured into ingot molds or sand molds with a taper, facilitating its later grinding and weight estimate, on remelting the metal in small furnaces.

The freshly prepared alloy is cleaned with a sandblast, stamped with the number of heat and, after receipt of the chemical analysis, sent to the production line for remelting and pouring into parts by precision casting.

Melting of Metal and Pouring of Molds

The pouring of molds in precision casting can be done either mold by mold or by groups of molds. In the latter case, the molds to be filled at the end must not be undercooled, since this may lead to defects in the casting. Practice has established that the conditions for the pouring of ceramic molds (which is the type of mold used in precision casting) may be considered almost the same, if the pouring is done within a period of 10-12 min from beginning to end of the pouring.

When molds are fired in continuous electric pusher furnaces, the delivery of each bottom plate with the molds takes place after a definite time interval ($1\frac{1}{2}$ to 2 hrs). This time must be precisely coordinated with the smelting, so that the molds do not have to wait for the metal, and the metal is not overheated waiting for the molds. In this case, all the molds of the bottom plate delivered from the furnace are poured simultaneously. The number of molds on a bottom plate must be constant and must correspond to the amount of liquid metal available in the furnace. Otherwise either liquid metal will be left over and must be cast into an ingot mold, which is very disadvantageous, or some of the molds will remain unpoured and must be scrapped.

The metal for pouring molds in precision casting is melted in furnaces of relatively small capacity. For this purpose an installation with machine generators of the type IV-60, with a furnace of 60 kg capacity, or high-frequency vacuum-tube installations with furnaces of 30-6 kg are used; the useoof automatic arc furnaces of 3-5 kg is not recommended, since they have not been fully developed. The small

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capacity of the melting furnaces is explained by the relatively small number of molds to be poured at one time.

The alloy, first melted and tested for chemical composition, is remelted in these furnaces under a flux. To the fresh alloy, 50-70% of plant waste may be added if it is suitable in its chemical composition (gates, risers, rejected parts.). To avoid high oxidation loss of the individual elements and oxidation of the alloy, remelting must be done within the shortest possible time.

Technology of Smelting Kh23N18 Steels. A heat of this steel, before pouring the molds (in a furnace of type IV-60) must be performed under the following conditions:

1. Clean the furnace, while hot, from slag and deposits, with a special scraper. Inspect the lining of the furnace and, if this is in satisfactory condition, place the furnace in the working position.

2. Charge all the fresh alloy into the furnace as tightly as possible. On top of the fresh alloy pack the plant waste (gates and rejects) up to the top of the furnace. The plant scrap must be cleared and sandblasted. Turn on the generator, the capacitor batteries, and the furnace. The power of the equipment, as read from a kilowatt meter, must not exceed 60 kw, and the voltage or the capacitor must not be over 600 v.

3. When the first liquid metal starts forming, add a flux of the following composition:

Unslaked freshly burned lime	80%
Metallurgical magnesite	15%
Fluorspar	5%

For the entire process of melting 60 kg of metal, 1.2-1.5 kg of flux is used.

4. Settle the charge and add the residues of the remelting, placing them on the still solid charge. If necessary to submerge the lumps of metal in the liquid bath, the metal to be submerged should be preheated by means of special tongs. As

the amount of liquid metal increases, keep adding flux in order to keep the entire liquid surface of the metal covered by slag at all times.

5. After complete melting of the metal, heat the bath to 1600°, as read from the optical pyrometer, remove all slag, and introduce 120-150 gm of finely ground preheated silico-calcium into the bath; then, mix the bath carefully and add new flux.

6. Heat the metal to 1520-1550°C, as read from the optical pyrometer and proceed to pouring the forms.

<u>Ladle for Pouring the Metal</u>. For pouring the metal, small graphite ladles (marks) are sometimes used. Alloys of high hot-strength are not sufficiently quiescent in such ladles; even in well-heated ladles, turbulence of the metal occurs, which can be explained by the intense burning away of the graphite. For this reason, special ladles, packed of chromomagnesite and magnesite, are generally used in pouring the molds for precision casting.

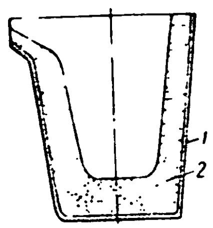

Fig.40 - Pouring Ladle

1 - Shell; 2 - Lining

The design of such ladles is very simple (Fig.40). In a cast or welded shell made of roofing tin, a lining slurry is packed onto the bottom. The slurry has the following composition:

Chromomagnesite, passed through No.12 screen	94%
Fireclay, passed through screen No.30	6%
1% aqueous solution of boric acid	7% (of the dry mix)

Instead of the boric acid solution, waterglass of 1.15 sp. gr. may be used (6-7% of the dry mix). The ladle is packed with the lining slurry up to the top, around a sweep which is then removed from the ladle. The lined ladle is dried in air for 12-20 hrs, after which it is placed for 1-2 hrs in the firing oven (together with the molds). The ladle is removed from the oven together with the molds before pouring, and placed in a special holder; the metal is then poured into the hot ladle.

According to the method of pouring adopted (mold by mold, or batchwise), the ladle is cleaned of deposits immediately after pouring, and is then again set for firing, together with the molds, until the following pouring. During pouring, a few such ladles must be kept in readiness to replace any that go out of service.

In precision casting during series work, strictly identical molds are generally used. These molds require the same amount of metal for pouring. In this case, the use of measuring ladles is recommended. Two-thirds the volume of these ladles is the volume of metal necessary for pouring the molds. The use of a measuring ladle filled with metal to a certain level, which is poured out completely into a single mold, greatly facilitates the work of the caster, since it guarantees against overflow of metal. A mark to indicate the necessary metal level may be made on the shell of the ladle with chalk, or it may be marked on the sweep during packing of the lining.

So-called teapot ladles have proved satisfactory for pouring molds in precision casting. Their design can be seen from Fig.41. This ladle retains the slag well and does not require manual skimming of the slag during pouring.

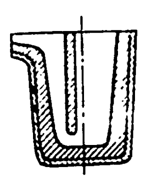

Fig.41 - Teapot Ladle

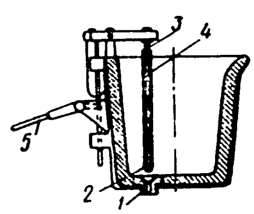

Fig.42 - Stopper Ladle

1 - Cylinder; 2 - Plug; 3 - Stopper rod; 4 - Chamotte tube; 5 - Lever device

In view of the small portions of metal used in pouring molds in precision casting, stopper ladles are rarely used. However, the use of rapidly oxidizing alloys of high hot-strength alloys makes it necessary to employ such ladles in pouring. Figure 42 shows an extremely simple stopper ladle which is opened and closed by hand. Such a ladle is a good catcher for the slag and oxide films floating on top.

Measuring the Metal Temperature. In pouring alloys of high hot-strength into the molds, the correctly selected and accurately measured metal temperature plays an important role. An optical pyrometer is used for measuring the temperature of the molten metal.

The principle of action of this instrument is based on a comparison of the luminescence emitted by the molten metal with the luminescence from the filament of an electric incandescent bulb in the instrument, fed from a dry battery. If the lens of the instrument is placed on the molten metal, the filament of the bulb is visible through the ocular against the background of the molten metal. By adjusting the brightness of the filament, the filament can be made to merge completely with the background; the filament, as it were, disappears from the background of molten metal. This indicates that the temperatures of the molten metal and the filament are equal. The temperature of the filament is graduated according to the strength of the current heating the filament.

Figure 43 shows the pattern as it appears in the optical pyrometer during a temperature measurement. In the position (a), the temperature of the filament exceeds the temperature of the metal (the filament is brighter than the background); in the position (b), the temperature of the filament is equal to the temperature of the molten metal (the filament has disappeared); in the position (c), the temperature of the filament is lower than the temperature of the molten metal (the filament is darker than the background).

The temperature data obtained with an optical pyrometer are comparative. However, when working under identical conditions, a pyrometrist who is familiar with the instrument and the measuring technique, can determine the ralative temperature with sufficient accuracy.

Pouring the Molds from the Ladle. After the metal has been heated to the necessary temperature and deoxidized, the foreman gives the order to pour. On a special pouring stand whose height is determined by the height of the molds and the convenience of pouring, molds in a number calculated from the available quantity of molten metal are stacked. Dry sand is sprinkled on the casting stand, to catch any metal spattered during the pouring. The molds are placed at intervals convenient for pouring from the ladle. The casting table is set up near the furnace, on a level surface.

a)　　b)　　c)

Fig.43 - Luminescence of Filament of Optical Pyrometer against Background of Luminescence of Molten Metal

By tilting the furnace, a portion of the molten metal is poured into the ladle. From the ladle the metal is poured into the mold. While pouring the molds with metal a founder's helper skims off the slag in the ladle with a special graphite scoop (skimmer) and sprinkles the pouring cup and the open risers with a heat-insulating mixture, consisting of 50% fired asbestos fines and 50% chamotte powder. Use of such a heat-insulating mixture ensures slow cooling of the risers and improves the feeding of liquid metal to the casting.

The pouring of molds with metal is one of the most important operations in casting. The quality of the casting depends largely on the height from which the teeming takes place, on the pressure produced, and on the absence of slag and other inclusions. In view of this fact, particular attention should be paid to pouring of the metal into the mold. It is the duty of the foreman and the founder to prepare each pouring carefully, to check the working position and equipment before

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casting, to inspect the molds, and to strictly assign the duties to all operators, so as to prevent unnecessary confusion during the pouring and to avoid oversights.

<u>Centrifugal Casting of Molds</u>. The insufficient strength of a fired ceramic mold and, in particular, its tendency to crumble prevents wide use of the progressive centrifugal method in precision casting. Centrifugal casting is most effective when metal shills are used. In precision casting, successful attempts are being made at present to cast parts by the centrifugal method; a number of parts are in fact already being cast in this way.

For centrifugal casting, centrifugal machines with a vertical axis of rotation are used. The face plate is actuated by a DC electric motor with adjustable rotor speed; the rotational speed of the face plate can be varied from 100 to 500 rpm.

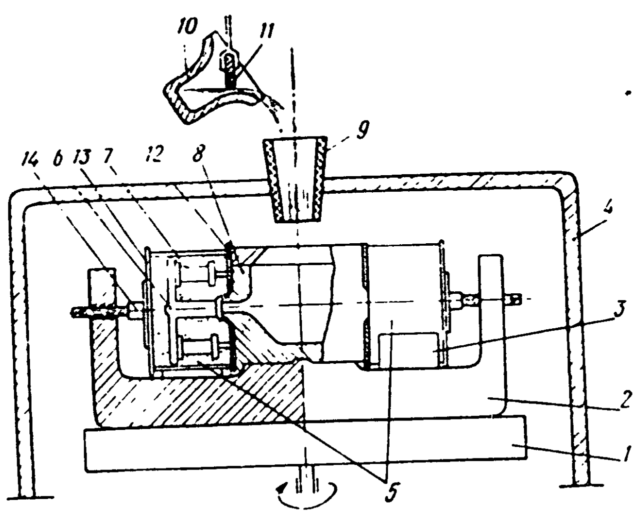

Fig.44 - Diagram of Centrifugal Casting

1 - Face plate of centrifugal machine; 2 - Cross piece; 3 - Prism; 4 - Shell; 5 - Mold; 6 - Gating system; 7 - Parts being cast; 8 - Metal receiver; 9 - Graphite funnel; 10 - Ladle; 11 - Skimmer; 12 - Asbestos gasket; 13 - Iron gasket; 14 - Clamp

The face plate of the machine carries a cross piece for installing two to four molds in accurately aligned prisms; the center of the face plate carries a ceramic well with branches known as metal ducts, against which the molds are pressed by screws. Between well, mold, and clamp, asbestos and metal gaskets are inserted (Fig.44). The molten metal is poured into the rotating machine. After the pouring, the rotation is continued for 5-6 min and the machine is then stopped, the molds and well are released, and the molds are removed and allowed to cool.

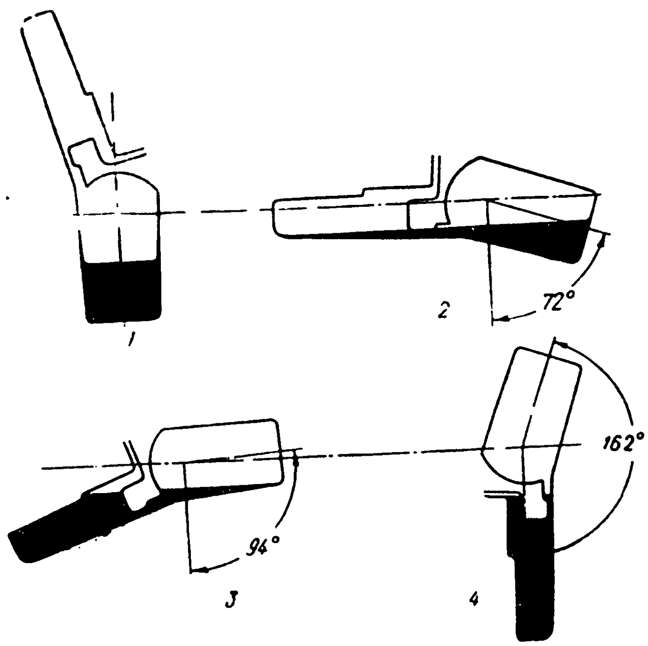

Fig.45 - Sequence of Filling Molds by the Mikulin-Bogoslovskiy Method

The well can be used for only one casting. It is made of moistened ceramic slurry, containing 40% of fireclay and 60% of chamotte grog. The wells are formed in metal core boxes by hand ramming; after molding they are subjected to natural drying, drying in driers, and firing together with the molds in the same ovens. Before drying, the wells are sometimes painted on the inner cavity and faces with a refractory wash of quartz flour and ethyl silicate.

With future improvement in the mold material, the method of centrifugal casting will undoubtedly be more widely used in precision casting.

Pouring the Molds under a Protective Atmosphere. Academician A.A.Mikulin, in collaboration with Engineer S.D.Bogoslovskiy, made a study of precision casting of parts from a strongly oxidizing alloy of high hot-strength and proposed an original method of casting, which sharply reduces the principal drawback of this alloy, namely the formation of oxide films.

In this method, the charge of such alloys consists of pure oxide-free metals, and melting and pouring the molds proceed rapidly in an atmosphere of argon gas, which prevents exposure of the metal to atmospheric oxygen. The molds are filled with the liquid metal, stream at low speed, using an arrangement of communicating vessels (Fig.45). In this arrangement, the crucible of the furnace, containing a measured portion of liquid alloy and equipped with an inspection window in its cover, and the gating passages in the cavity of the mold, form a system of communcating vessels as soon as the entire system is rotated. The rate of filling of the mold with liquid metal is regulated by the rate of rotation of the furnace-mold system.

The installation for melting metal and pouring the mold by this method includes, besides the argon system, a high-frequency melting unit with an electron-tube generator of 60 kw power. At a frequency of 150-200 kc, the unit will melt 6 kg of steel and heat it to 1550°C in 8-10 min.

The rotary melting furnace (Fig.46) of a capacity up to 10 kg, is equipped with a packed chromomagnesite crucible. By means of a reducer, the oven can be rotated through 180° in 4, 6, 8, 10, or 12 sec. The mold to be filled with metal is in metal core boxes by hand ramming; after molding they are subjected to natural drying, drying in driers, and firing together with the molds in the same ovens. Before drying, the walls are sometimes painted on the inner cavity and faces with a refractory wash of quartz flour and ethyl silicate.

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attached to the furnace by means of a hinged cross piece.

The melting of strongly oxidizing alloys and their pouring by this method

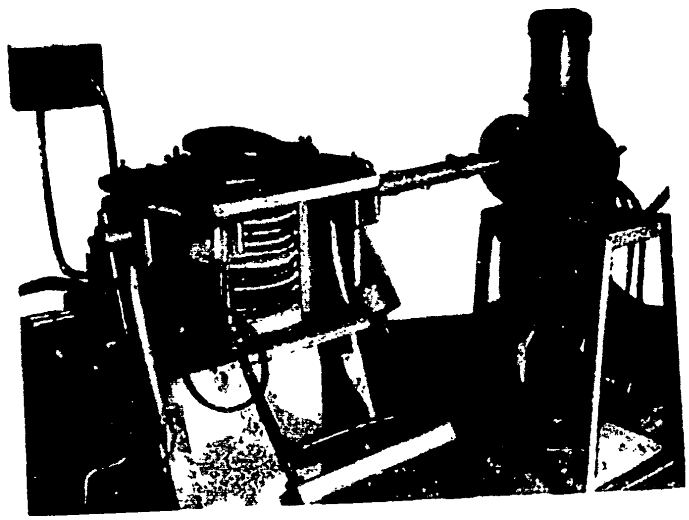

Fig.46 - Rotary Melting Furnace with Reducer (Covered with a Graphite Cover, used as the Base for the Mold)

greatly improve the quality of the castings, the more so since this pouring eliminates handwork and all deviations that are inevitable in hand casting, allowing automation of the process of pouring the molds.

X. KNOCKOUT, TRIMMING, AND CLEANING THE CASTING

Knockout of the Casting

Premature knockout of the castings from the molds is undesirable, since this may lead to buckling of the castings. The cooling time of the castings in the molds depends on the weight of the castings. The cooled molds are sent to the department.

The knockout of the molds in precision casting is done with an aluminum sledge-hammer, on knockout screens, or on vibrating beams. Castings with particularly intricate details are sometimes knocked out by means of a sandblast device. In this case, particular care must be taken to avoid damaging the fine edges of the part during the knockout. In addition, when molding has been done in flasks of fire-resistant sheet steel, inaccurate mold extraction will lead to extensive buckling of the flasks, and to their premature unfitness for service.

Not all molding materials behave in the same way during extraction, when the molds have been normally fired. Molds formed with a dry facing, without plugs (using boric acid) are extracted with considerably more difficulty than molds with plugs and with alumina cement (liquid filler). Monolithic molding mixtures that are difficult to knock out should be removed only by mechanical devices. The molding mixture most widely used (liquid filler with alumina cement) is easy to knock out by any method of extraction. The conditions of firing the molds can be judged from the knocked-out molding mix. A mix in normally fired molds has a uniform pinkish color. In poorly fired molds, however the color of the molding is a normal pink in the outer layer but a dirty gray, sometimes changing into almost black, at the center of the mold.

During the knockout process, the castings are not completely freed of the molding mix. The facing layer of the mold is partially burned onto the castings. Complete cleaning of the clusters of castings from the molding mix and the facing is done by sandblasting them on a sandblast machine.

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The sandblasted casting clusters are routed to the trimming department for removal of gates and air holes.

Cleaning the Castings

Since high-alloy steels and alloys of high hot stress-strain values are the metals mostly cast by precision casting, the removal of gates and air holes from the castings with ordinary cutting tools (cutter or miller) on metal-cutting machine tools is very complicated.

The cleaning of precision castings by vulcanite cutting wheels of 2.5-3.0 mm thickness on high-speed machine tools (2000-2500 rpm), on special attachments for this purpose, is practiced widely. But even this method of cleaning precision castings is not satisfactory, since it involves frequent wheel breakage, high wheel replacement, and relatively high losses of expensive metal in the grinding dust.

The most rational equipment for the cleaning of precision-cast parts obviously are machines for anodic cutting.

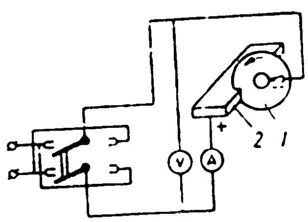

Fig.47 - Wiring Diagram of Cutting
1 - Cutting Disk (cathode); 2 - Part being cut (anode)

Anodic cutting of metals is based on the simultaneous use of the electrochemical, thermal action of the electric current and on the mechanical action on the part being cut, which is connected as the anode in a direct current electric circuit. The tool used for cutting, in most cases, is a thin rotating iron disk, whose function is not so much the removal of chips from the part, as the application of a cathode current at the place of cutting (Fig.47).

A special working fluid is fed to the cutting point of the part, i.e., to the point of contact between the two electrodes. Under the action of the direct current, a film of high electric resistance is formed at the cutting spot. The rotating disk removes this film, but, under the action of the working fluid and the direct current, the film continuously re-forms. While work is done at the cutting point, the thickness of the film decreases, allowing a current of high density to pass, which fuses the metal. Anodic cutting is thus, more exactly, a melting of the metal on a very narrow area (the thickness of the disk). This area is as deep as the distance to which the disk penetrates.

The narrow layer of metal melts so rapidly that the part has no time to heat up.

The following factors determine the technological process of anodic cutting:

1. Electric Conditions. Usually the voltage of the equipment is 20-28v; the current strength depends on the size of the part to be cut and is usually within the range of 40-350 amp, with the diameter to be cut ranging from 10 to 250 mm.

2. Relative Pressure between the Electrodes. This depends on the feed of the cutting disk and is selected during the operation from the readings of the ammeter and voltmeter. The optimum pressure on the area of contact between disk and part along the cutting arc ranges from 0.5-2.0 kg/cm^2.

3. Peripheral Speed of Cutting Disk. The peripheral speed of the disk is selected according to the diameter of the part being cut. For small diameters, up to 12 mm, the peripheral speed of the disk is 7 to 9 m/sec. For larger diameters to be cut, with a disk of 400-700 mm diameter, the peripheral speed may be 16-20 m/sec. Since the cutting disk is worn during operation and its diameter decreases, a certain reduction in the speed is possible, and must be allowed for in determining the rated speeds.

4. Amount of Working Fluid. Liquid is necessary for film formation at the cutting place of the workpiece; it also performs the function of a coolant. From operating experience, the following relationship has been established between the diameter of the part being cut and the amount of working fluid:

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Diameter of Part being Cut, in mm	Amount of Working Fluid in liters/min
To 30	5-10
20-100	10-15
100-200	15-20
200-300	25-30

The working fluid is supplied by a pump through a nozzle to the cutting point. It must bathe the cutting disk and fill the cavity of the cut. The suitability of the working fluid is determined from its purity (absence of admixtures) and its specific gravity.

The design of the cutting disk is also of great importance for operation of the installation. No vibration of the cutting disk is permissible.

Figure 48 gives a sketch of the AMO-32 machine for anodic cutting. The technical data of this machine tool are as follows:

1. Maximum size of work piece to be cut	100 mm
2. Maximum diameter of cutting disk	420 mm
3. Peripheral speed of cutting disk	16 m/sec
4. Feed of cutting disk	automatic
5. Delivery of pump	15 liter/min
6. Density of working fluid	1.29-1.3
7. Power of electric motor (driving the disk)	2.2 kw
8. Dimensions of the machine:	
Length	1310 mm
Width	760 mm
Height	1376 mm
9. Weight of machine	700 kg
10. DC voltage	20-25 v
11. Current intensity	up to 200 amp

Welding generators of the type SMG-1, SMG-2 of the "Elektrik" plant, the

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NDSh type galvanic generator, and certain others, are used for supplying direct current for feeding the anodic machine tools.

A clamping attachment (cf.Fig.48) installed on the machine allows the anodic cutting of laminates. Two corrugated surfaces and a plunger reliably hold any rod material.

Special replaceable attachments must be installed on the machines for cutoff of the castings from the jigs. In series production, such attachments are required for each gating system used. If small batches of castings are produced, universal vises, usually installed on milling machines, can be used.

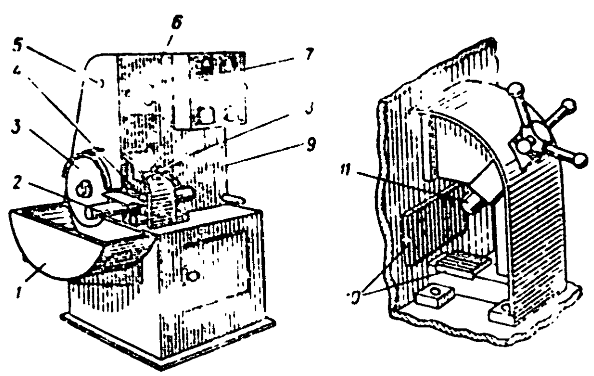

Fig.48 - AMO-32 Machine

1 - Trough; 2 - Workpiece to be cut; 3 - Disk; 4 - Nozzle; 5 - Rocking Axis of disk; 6 - Handle for feeding and withdrawing disk; 7 - Instrument panel; 8 - Clamping attachment; 9 - Stand; 10 - Bearing Surface; 11 - Clamp plunger

In conclusion, it should be noted that certain nickel or cobalt base alloys of high hot strength, after cutoff by the anodic method, must be carefully washed in a hot-water bath and then sandblasted, since the alkali in the working fluid has an unfavorable effect on the metal, especially during the subsequent heat treatment of

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the parts and in melting contaminated gates and risers.

Trimming the Castings

The cleaned castings are routed to the fitters' trimming department.

When all operations of precision casting are conducted normally, the castings, as a rule, have a good surface finish. The gate stubs are usually trimmed off (to an extent agreed on with the machine shop), if it was not possible to cut them off exactly. The castings are trimmed or dressed on emery grinding wheels.

Individual casting defects are also subjected to trimming. Along the radii, fillets, and sharp edges, roughness and outgrowths of metal due to inadequate strength of the mold coating are often found. Such defects are removed with abrasive sive wheels and small abrasive cylindrical and conical balls on a ceramic band (electrocorundum disks and balls of SM_1 and SM_2 with a ceramic band may be recommended). Fillets of small radius and relatively long extension along a curved line are conveniently removed with a shaped abrasive disk or a thin cutting disk on a vulcanized band. Abrasive wheels are most conveniently used on special high-speed polishing heads. Balls are usually placed in pneumatic drills.

Fine edges of the parts are trimmed with files and emery strips.

In all forms of cleaning of precision castings, the very narrow tolerances which these castings must meet, must be considered. Incorrect cleaning may bring a casting outside of the tolerance range and cause its rejection.

After cleaning, the castings are routed for a second sandblasting. The sandblasting of precision-cast parts must be made with fine river sand, at an air pressure up to 4 atm. The small parts are sandblasted at high speed. It must be remembered that sandblasting is a very powerful method of treating parts with an abrasive. When the nozzle of the sandblasting chamber is close to the part, a hole is blasted into a wall of 1.5-2 mm thickness is blasted in 1.5-2 min.

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Machining of Precision Castings

The manufacture of castings to high accuracy and high finish makes it possible to send most parts to the assembly without machining or with only a slight machining of the fit joints, sometimes with a decorative polishing.

But many parts, especially those of alloys with high hot strength require accuracy and finish beyond that now provided by the method of precision casting. Such parts are machined. Precision castings are made to very low tolerances (0.2-1.5 mm) so that standardization of the bases for measurements in the foundry and for machining and measurement of castings in the machine shop becomes of primary importance. We recall that the basic surface or basic points on the parts are the surfaces and points by which the part is oriented with respect to the cutting tools, during machining. It is only natural that in the foundry and machine shop the measurement and machining of precision castings should be performed relative to one and the same basis.

Sometimes a cast unmachined surface is taken as the base, but in some cases a machined surface of a detail may also serve as the primary base. In the latter case, it is more convenient for an objective evaluation of the castings produced in the foundry shop to establish this primary base in the foundry shop, by performing the necessary machining of the base surface right there.

Buckling of castings leads to considerable trouble in machining. For this reason, before the castings leave the foundry, a check test must be run to determine whether the buckling of the castings exceeds the established tolerance. Castings exceeding the buckling tolerance must be trued.

It is preferable to true the castings on specially adjusted dressing swages with inverse buckling, by bending on manual or hydraulic presses. Sometimes castings are trued manually with a bronze hammer on special straightening presses, but this method does not give consistent results, and impairs the quality of the castings (sink-marks). It also increases the amount of labor necessary, and should thus be avoided as much as possible.

In cases where the material of a casting does not permit trueing to correct buckling, the tolerances must be increased. The character of the tolerances determines the method of machining precision castings. In most cases, the parts are machined by finish milling and grinding, but sometimes only by grinding and polishing.

Thin-walled open-work parts are usually manufactured by the precision casting. When clamping them into the attachment for machining, it must be remembered that the parts may buckle under the force of the clamping, which, if the tolerance is small, may lead to rejection for surface roughness of the part on the side away from the clamp.

In machining precision-cast parts, the adapter method has become widespread. The procedure is as follows: The casting is placed into an accurately dimensioned attachment designed for the machining of all or most of the surface of the part, is clamped into the attachment, and is not removed from it until the machining of all necessary surfaces has been completed. This method is less productive and requires a large number of precisely machined attachments (adapters), but it increases the accuracy of machining at a single insertion of the part.

In series production, the method of machining precision castings on multi-position attachments is widely used.

In the machining of precision castings, a correct adjustment of the attachments and the layout of the process is of great importance. Series production provides for the machining of large batches of parts, so that any inaccuracy in the adjustment of machining processes may lead to rejection of a large number of castings, in view of the extremely narrow tolerances for such castings.

XI. SPOILAGE IN PRECISION CASTING, QUALITY CONTROL, AND MEASURES OF REDUCING SPOILAGE

During the first stage of introduction of precision casting, the high percentage of rejections was one of the serious obstacles to the mass use of this new method of production. At present, all the enterprises that cast parts by this method have done a large amount of work in the control of spoilage. The overwhelming majority of defects that are met have been studied, and ways of eliminating such defects have been mapped out.

In his report to the 19th Congress of the Party, Comrade G.M.Malenkov said: "In many enterprises, large losses occur because of the uneconomic consumption of materials, raw materials, fuel, electric power, tools, and other material values; the established consumption standards are frequently violated, and the introduction of adequate substitutes is neglibible; the rejection rate in production is still high". Comrade Malenkov went on to say that the majority of losses and unproductive expenditures in industrial enterprises are the result of spoilage.

"The task is", he went on to say, "To end this indifferent attitude of management and Party organizations toward waste and extravagance" (Bibl.18a).

These statements by Comrade Malenkov are fully applicable to founders, since the spoilage in foundries is still excessive.

Causes of Defects, Types of Defects, Remedies

Causes of Defects. The most general causes of defects in precision casting can be divided into three groups:

1. Defects due to incomplete finishing of the design of the part. A design of the part, insufficiently thought out, may lead to defects of the widely varying types, faulty geometry, and casting and metallurgical defects. These forms of defects are produced when the designer, in his effort (for example) to reduce the weight of a given part and their number in a unit, neglects to consider the technological possibilities and prescribes wall thicknesses unsuitable for casting, or unproducible because of intricate contours of the part. These same types of defects will occur in the work when the casting engineer submits a poor foundry drawing and does not instruct the designer to modify the design to make it more suitable for the technology of casting. This does not mean that the designer cannot give complex

casting problems to the process engineers or that the founders should cast only simple parts. Precision casting can handle the production of very intricate parts. However, a thorough discussion of the design of a part as well as creation of the design of a part best suitable for actual production are of extreme importance, and favor the reduction or elimination of casting defects.

There should be no defects due to inadequate development of the design of a given part. Such a thorough development of design is possible if the designer and the process engineer cooperate closely. This collaboration is not confined to coordination of drawings. Success may also demand experimental castings of parts, which always has a favorable effect on the final modification of the drawing.

2. Defects from failure to work out the process. This is the most insidious cause of defects and is unfortunately the form most often encountered in precision casting.

The process chart for casting a part should take into consideration all possible bugs in the process, that might result in defects. The process engineer must carefully think through and test, on experimental castings, all operations, transitions, and working methods. He must check on the necessity and suitability of the materials selected and of the operating conditions prescribed for the equipment. He must design the necessary production and control facilities. The process engineer must make certain that the process designed by him guarantees 100% yield of sound castings, and that any defective casting must merely be the result of some violation of the process conditions. No obscure spots must be left in the process. There is no excuse for cases in which a constantly recurring (even if less often) defect has not been investigated, even if the process conditions were consistently followed. To disregard such a "wandering" defect would mean to leave the process to chance, i.e., to leave the defect without eliminating it.

Each type of defect must be studied individually. The causes for such a defect must be clear. All measures to eliminate a recurrence of the causes must be taken. Such measures must be clearly reflected in the process conditions and must be meticulously observed in the production line.

In solving the complex problems that confront casting process engineers while laying out a process, the engineer should be given the necessary support by the shop and plant management as well as by foremen and workmen-innovators, whose many years of practice, experience, and initiative may considerably facilitate and speed up the improvement of the process.

Even what might, at first glance, be the best process (and, indeed, every good technological process) can and must be continuously improved and perfected, relying on the accomplishments of soviet technology, on the conquests of Soviet science, which lighten the work of the workmen, by mechanizing and automizing the processes. This task can be fulfilled by the united efforts of the entire personnel of the shop and plant.

3. Defects due to violation of the process conditions. Defects from this cause may arise in any operation and in any transition. Failure to observe the temperature conditions in the melting of metal and in firing and drying of the molds; careless preparation of materials for work; poor condition of the equipment and implements; carelessness in work, will all increase the amount of spoilage and rejects.

A constant struggle must be waged against violations of the process conditions in departments and shops devoted to precision casting. Each case of violation of the process conditions should be the subject of a discussion, and measures should be taken by the shop administration for each case of violation of the process conditions. Those who violate the process conditions must be held financially responsible.

In this respect, the role of the foreman in the department is very important. A negligent foreman, indulgent to violators of the process conditions, who permits violations of the process conditions, can transform any literate and well laid-out process chart into a useless scrap of paper and may do great damage by producing defective articles. The foreman should participate in establishing the process conditions. He should agree with the process engineer on the performance of all operations in accordance with the process conditions, but he should never in any way violate the process conditions, once established. The foreman must indoctrinate every workman on the process conditions and make sure that the latter has thoroughly mastered the operations assigned to him.

It is only by specific permission of the chief engineer of the plant, for reasons of industrial necessity, that occasional deviations from the process conditions may be authorized, and then only after serious consideration. Each case of such a deviation should be formalized by a special plant memorandum, or must be justified by a serious reason, for example, by damage to the equipment.

Let us now consider the types of defects met in precision casting, which may be connected with pattern defects, poor mold quality, casting and metallurgical defects.

Spoilage due to Pattern Defects. All defects of the patterns are reflected in the casting with almost photographic rendition. The unevenness of individual edges, scratches and lines, blowholes and bubbles, foreign inclusions in the pattern material, always are transferred to the metal casting and unfavorably affect its appearance and quality. The quality of the material used for the patterns and of the raw materials for the mold slurry, largely determine the soundness of the patterns and castings.

The raw materials for the pattern composition must rigidly conform to the approved specifications. They must be free from foreign inclusions and must meet the delivery conditions. High ash content of the pattern is impermissible. The process of pouring the patterns is of great significance for the quality of the patterns.

The forms of casting spoilage or scrap due to defects in the patterns, the causes of such defects, and the remedies are given in Table 30.

Table 30

Types of Pattern Defects and Castings Defects Due to the Patterns			
No.	Type of Defect	Cause of Defect	Remedies
1	Failure to fill, welding, cold shut	a) Cold pattern composition	a) Do not forward defective patterns to further processing. Determine temperature conditions for filling patterns more precisely
		b) Incorrect system of supplying molten pattern material to die	b) Correct gating system in die
		c) Violation of conditions for pattern making	c) Carefully check temperature conditions
2	Shrinkage cavity in pattern	a) Overheated pattern mixture b) Insufficient pressure when pouring patterns	a) and b) Define and observe temperature and pressure conditions during pouring
3	Cracks in pattern	a) Cold die	a) Heat die
		b) Local defects (undercutting or fin) in die, great clearances on joints of dies, increas-	b) Correct defect in die

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No.	Type of Defect	Cause of Defect	Remedies
		ing the seams on the patterns c) Prolonged residence time of pattern in die after pouring	c) Work out conditions for holding pattern in die for optimum result. Scrap patterns with cracks
4	Blowholes (air bubbles) in patterns	a) High temperature of pattern mix being poured b) Incorrect supply of molten pattern material to die	a) Work out temperature conditions of pouring, carefully observe process conditions for pouring patterns b) Correct gating system in die. Scrap patterns with air bubbles on working surfaces. On nonworking surfaces and in the mating parts of the pattern, the air holes may be filled in with an electric soldering iron and molten pattern material
5	Clogging of Patterns	a) Use of contaminated raw materials with high ash content for boiling the pattern mixture	a) Use materials meeting the approved specifications. Filtering individual contaminated materials through a No.140 screen after first melting

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No.	Type of Defect	Cause of Defect	Remedies
		b) Untimely and poor cleaning of thermostat or electric bath	b) Timely and thoroughly clean equipment and ventilating system
		c) Lack of necessary cleanliness at working position for preparation of pattern material and patterns	c) Maintain the necessary cleanliness at the working positions in the pattern department
6	Distortions of geometrical dimensions of pattern	a) Wear of die	a) Check and correct die as to worn insert
		b) Buckling of low-melting patterns	b) Maintain optimum temperature of 15-25°C in room of model department. Store patterns correctly on special racks to avoid possible buckling of patterns from their own weight
		c) Incorrect removal of patterns from die	c) Correctly remove pattern from die
		d) Tearing of pattern during cleaning and assembly	d) Clean model according to standard. Scrap patterns with defects on unworked surfaces. Correct other defects

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Molding Defects

Table 31 gives the following forms of casting defects due to poor quality of the mold.

Table 31

Forms of Casting Defects Due to Poor Quality of Mold

No.	Type of Defect	Cause of Defect	Remedies
1	Local overflow of metal onto casting surface (Fig.49c). Often has the form of external seam with traces of the destroyed facing layer (Fig.49N). Sometimes with pinchers in the part (For Fig.49, see	a) Crack in one or more facing layers	a) Observe optimum temperature conditions at 15–25°C in coating and molding parts. Do not allow subsequent rapid coating of poorly dried-out cluster. Do not allow irregular thickness of facing layers. Carefully treat the parts in ammonia. Limit size of batch to be treated at the same time to 50 clusters, since larger numbers vary the conditions of drying. Maintain relative humidity of room at not lower than 35–40%
		b) Inadequate packing of mold at given place	b) Apply special paste of quartz sand, ethyl silicate and magnesia, and thoroughly coat with a thick layer of this mixture the cluster of

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No.	Type of Defect	Cause of Defect	Remedies
			already coated patterns on surfaces hard to reach for the molding. During molding, use elastic spatulas.
		c) Cracks in mold during process of drying and firing	c) Strictly observe established conditions of drying and firing molds, without allowing charging of molds into oven at elevated initial temperature. Do not shorten the duration of the established stages of drying. On molding in flasks line its inner walls with paper (thickness of paper layer 0.2-0.3 mm).
		c) Careless handling of mold (impact) during charging into drier and oven and during unloading	d) Carefully charge, unload, and transport the molds, protecting them from impacts and dropping. Do not pour damaged molds.
2	Clogging (Fig.49M)	a) Cracks in facing layer of mold and collapse of part of investment	a) Same as in 1a

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No.	Type of Defect	Cause of Defect	Remedies
		b) Cracks in mold and dropping of fired molding mix inside mold	b) Same as in 1c
		c) Disintegration of mold by jet of steam or air	c) Exactly align molds with the gate on the nozzle with steam or air
		d) Mold crumbles after firing	d) Strictly maintain time of packing on vibrator. Replace or add alumina cement
		e) Sand or earth falling into cavity of mold	e) Molds should be stored, transported and charged, with the pouring funnel down. Close the opening before pouring the molds
		f) Breaking of the solid crust on the face of the mold on the side	f) Carefully remove mold from flask board. Clean the boards before molding. Coat the boards with machine oil. In molding the upper and lower layer of the mold, fill with a mixture having a high content of alumina cement (perform the molding with two facing mixes

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No.	Type of Defect	Cause of Defect	Remedies
3	Unsatisfactory finish of casting surface	a) Low refractoriness of facing layer of mold	a) Test raw materials for investment layer for content of oxides of calcium, magnesium, iron, and alkali metals. Purify quartz flour by thoroughly washing it followed by firing
		b) Too coarse screening or entry of large fractions of quartz dust into coating	b) Check screen for sifting quartz dust and rescreen quartz dust through No.140-200 screen
4	Gas holes	a) Insufficient drying and firing of molds	a) Strictly maintain conditions of drying and firing of molds. Eliminate suction under oven drawers. Do not stand molds for firing close to each other or to the doors of the oven
		b) Low gas-permeability of molding mix	b) Increase gas permeability and test for grain size of molding sand

<u>Casting and Metallurgical Defects</u>. The types of defects belonging to this group (Table 32) are of the greatest importance among the defects of precision castings. While all above-listed defects are relatively easy to eliminate by exactly following the established process conditions, casting and metallurgical de-

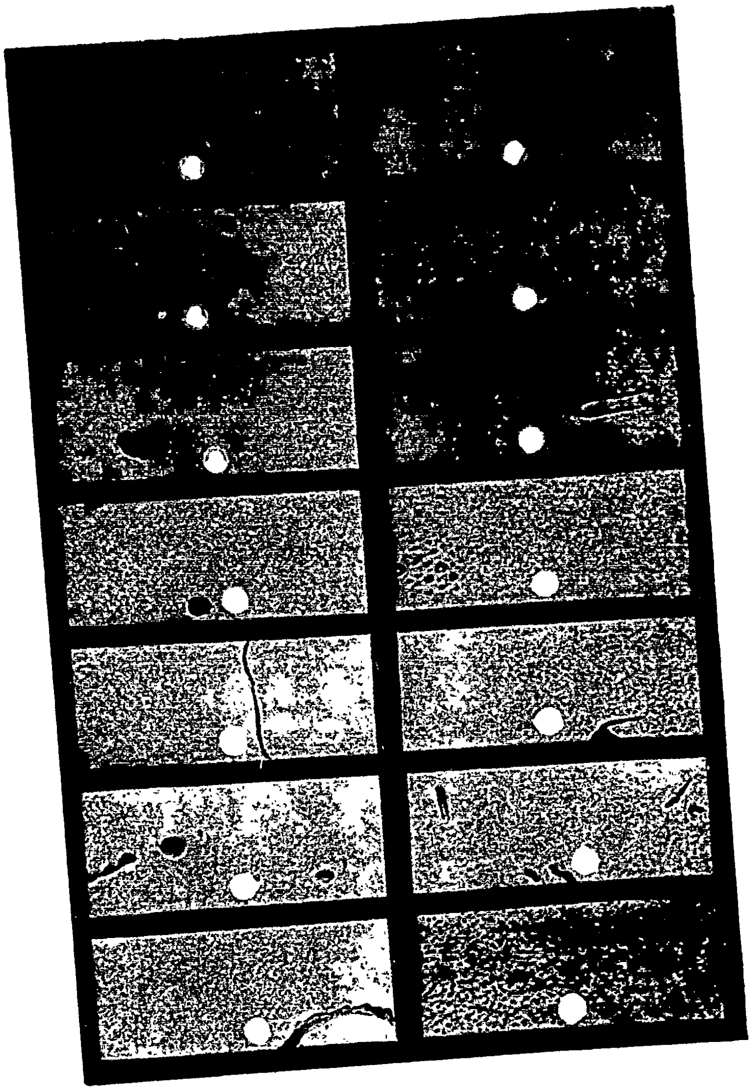

Fig.49 - Types of Defects (On Thin Plates)

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fects largely depend on manual methods of a given operation, which cannot always be specified accurately in a process chart. For example, the process chart states: "On teeming the metal from a ladle, retain the slag with a graphite skimmer". The performance of this operation, even with extreme care, does not guarantee complete prevention of slag inclusions; for this reason, important points in the control of casting and metallurgical defects include improvement of the process conditions, mechanization of the process, and creation of better gating systems, since the correct technological solution, by way of process modification may often be the only way to eliminate such defects. As a rule, before a part is placed in series production, a casting or a batch of castings is subjected to a complete metallurgical study. The part can be placed in series production when macro and microstructure of the castings, quality of the fractures, x-ray pictures, mechanical properties, and chemical composition of trial castings meet all specifications.

Table 32

Types of Metallurgical and Casting Defects

No.	Type of Defect	Cause of Defect	Remedies
1	Shrinkage cavities, looseness and porosity. Open or covered cavities in casting, sometimes accompanied by shrinkage of casting. Surface of shrinkage cavities is often oxidized.	a) Reduction in volume of metal during cooling in liquid state, in the process of solidification. Often accompanied the appearance of a shrinkage cavity which leads to looseness of the metal in the layers adjoining it and to	The fundamental measure to eliminate these forms of defect is correct feeding of the casting with liquid metal. Install over each solid place in the casting a riser whose dimensions must be greater than the dimensions of the bulge in the casting

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No.	Type of Defect	Cause of Defect	Remedies
		porosity, due to inadequate feeding of these layers with liquid metal. b) Overheating of individual cross sections of casting, due to passage through these cross sections of masses of hot metal, and to premature solidification of the portions of the casting that feed this cross section. c) Interruption in the feed of any area of the casting during the period of solidification	to be fed. An open cylindrical riser must have a height-diameter ratio of 1.5 : 1. The horizontal cross section of an open riser must exceed the cross section of the bulge being fed in the casting by not less than 25%. If closed risers are used, so-called atmospheric risers, which communicate with the atmosphere by a special gas-permeable core, will give a greater effect. Ensure directional solidification of the axial layer of the metal, for which: feed the riser with hot metal by the shortest route from the pouring cup; cool the parts of the casting most remote from the riser by means of special technological runners or fins acting as coolers, the

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No.	Type of Defect	Cause of Defect	Remedies
			installation of which is difficult in precision casting; avoid unbalanced risers, where the riser is fed from another riser through the casting. Correctly conduct the metal to the casting, for which: avoid as far as possible conducting the metal through thin cross sections of the casting; separate the flow of hot metal into as many streams as there are bulging parts in the casting. Keep the open risers warm in the castings by means of a heat-insulating agent which prevents rapid solidification of the riser.
2	Hot tears, surface or through breaks in the casting walls. Surface of break is oxidized.	a) Insignificant pliability of mold material, preventing normal shrinkage of solidifying metal.	a) To make the mold more pliable, the time of vibrating the mold during its packing must be shortened. Reduction in the alumina

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No.	Type of Defect	Cause of Defect	Remedies
			cement content of the mix is also helpful. These measures are possible within certain limits, since excessive weakening of the mold may lead to crumbling.
		b) Presence of shrinkage cavities and looseness, weakening the cross section of the casting, at stressed places in the casting	b) Ensure sound casting without shrinkage cavities and looseness, by using a more rational gating system (cf. Section 1)
		c) Sharp transition in casting from thick to thin cross sections. Presence of sharp faces and angles in casting, where stresses are concentrated.	c) Design modification of part or correction of foundry drawing (provide for smooth transitions from thick cross sections to thin ones, eliminate sharp angles and faces); it is possible to use special shrinkage fins which are made on the patterns at places subjected to hot tears on casting.
		d) Too high a content in the steel or alloy of harmful impurities (sul-	d) Ensure minimum content of harmful impurities, for which purpose the remelt

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No.	Type of Defect	Cause of Defect	Remedies
		fur and phosphorus)	metal must be regenerated and pure raw materials must be used in steel or alloy making. Such materials must have a minimum sulfur and phosphorus content.
3.	Cold tears - tears in body of casting, with unoxidized surface. The fracture is granular and sometimes has an oxide tint	Principal cause of the appearance of cold tears are internal stresses in the casting, during solidification; the causes indicated in item 2 also have an effect on the formation of cold tears	Special coolers to equalize the cooling of all parts of the casting are not yet used in precision casting. The measures indicated in point 2 (b, c, and d) have the greatest effect in the control of cold tears; rational heat treatment of the castings, in order to remove the internal stresses, is also very effective.
4.	Wrong chemical composition of alloy (determined by chemical or spectroscopic analysis of test specimens)	a) Use of low-grade original charge material in smelting fresh alloy.	a) This cause is usually the most widespread in deviations in the chemical composition of the alloy. The only charge materials that should be used for the heat are approved brands with

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No.	Type of Defect	Cause of Defect	Remedies
			obligatory checking for the presence of certificates. Control analyses for the principal elements and harmful impurities are run periodically. The original charge materials must be properly stored by brands.
		b) Deviations in the process of smelting the alloy and its subsequent remelting before pouring.	b) Check the calculation of the charge, the correctness of the weighed portions, and the order of charging the materials at the time of melting. Do not allow the smelting process to be drawn out during the smelting of the alloy and its remelting.
		c) Contamination of remelt metal by unbranded scrap	c) Organize proper storage of remelt metal, not allowing its contamination by unbranded metal in the charging yard. Isolate alloy that is not conditioned according to chemical analysis, allowing it to be used in a charge only in calculated quanti-

No	Type of Defect	Cause of Defect	Remedies
			ties pursuant to special technological instruction.
		d) Elevated oxidation loss of individual elements of alloy	d) On remelting, do not prolong the process of melting, since this increases the oxidation loss of individual elements, and must sometimes be compensated by a special composition of flux and by addition of individual elements.
5.	Failure of alloy to meet specifications as to mechanical properties and structure (determined by testing control specimens at the plant laboratory)	a) Failure of chemical composition of alloy to meet specifications	a) In various alloys, the deviations in the content of the individual elements lead to impairment of mechanical properties. An elevated content of harmful elements and impurities is impermissible. Since they also lower the physico-chemical properties of the alloy. The measures to eliminate this defect are indicated in point 4 (a-d).
		b) Elevated pouring temperature	b) Lower pouring temperature of alloy if this does not

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No.	Type of Defect	Cause of Defect	Remedies
			result in casting defects.
		c) Incorrect heat treatment	c) Determine conditions of heat treatment more precisely
		d) Casting defects of castings or test specimens	d) Ensure production of sound castings with respect to defects. Thoroughly deoxidize alloy.
6.	Gas holes (Fig.49g). Open or internal cavities in casting with clean and rounded inner surface. Isolated and group gas holes are encountered. The holes located in a group on the surface of a gas hole are sometimes called "rash" when they are small.	a) Use of oxidized, damp charge materials	a) The ferro alloys used must be heated. The remelt metal is sand blasted before being added to the heat.
		b) Inadequate deoxidation of alloy.	b) Poorly deoxidized quantity of absorbed gases. Before pouring, the alloy must be thoroughly dioxidized.
		c) High temperature (overheating) of alloy	c) Do not overheat alloy; take the metal from the furnace at the established temperature. The gas-saturated alloy should be held before pouring in the ladle, to give the gas an opportunity to escape from the metal.
		d) Gas liberation by mold	d) The mold should be thoroughly fired before pouring.

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No.	Type of Defect	Cause of Defect	Remedies
			The permeability of the mold must ensure dissipation of gases from the mold, not into the metal but into the outside air, for which the permeability of the facing layer of the mold bust be less than the gas permeability of the filler of the mold. The permeability may be increased by making holes in the mold or by providing special gas outlets in the pattern cluster.
		e) Incorrect pouring.	e) Pouring of an interrupted stream is not permitted, since in this case the air will enter the mold with the metal. The thicker the walls of the casting, the lower must be the pouring temperature
		d) Insufficient firing of the linings of melting furnace and ladle.	f) Fire the ladle of the furnace before the heat. Use a hot ladle in pouring, heated to a temperature not lower

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No.	Type of Defect	Cause of Defect	Remedies
			than 700-800°C. The tapping spout must be thoroughly dried.
7	Sand holes (outer or inner small cavities in casting filled with molding material, (Figs.49 d and e).	a) Washing away of mold walls by metal.	a) Pouring must be made quiescent, for which purpose: use slit feeders; reduce the height of the head and rate of pouring; use retarding gating systems; direct the jet of metal along a tangent to the mold and avoid straight runners; use the method of siphon pouring.
		b) Insufficient strength of mold and facing layer	b) Cf. forms of mold defects (items 1 and 2)
8	Slag holes (outer or inner cavities in casting filled with slag, Fig.49 n and k).	a) Entry of slag into mold during filling.	a) In filling through the top of the ladle, hold the metal in the ladle and allow the slag to float. Remove the slag and retain the remnants of the slag during pouring by means of a graphite skimmer. Use stopper and teapot ladles in pouring. Carefully line and dry the melting furnace and ladle.

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No.	Type of Defect	Cause of Defect	Remedies
		b) Formation of secondary slag on reaction of metal with ladle lining and mold material.	b) Use special slag traps in the gating systems.
9	Buttons - small solidified and oxidized globules of metal entering the casting.	a) Turbulent filling of molds, accompanying by splashing and spattering.	a) Pour the mold in a quiet and continuous stream.
		b) Same as in the formation of gas holes.	b) See item 6 (a, b, e)
10	Metal penetration (Fig.49 n)	a) Melting of facing layer of mold in contact with molten metal as a result of inadequate refractoriness of the mold, or chemical reaction.	a) Thorough preparation of facing layer of mold (its freedom from low-melting impurities); lowering the pouring temperature.
		b) Penetration of molten metal into pores of mold.	b) Increasing mechanical strength of facing layer of mold; correct selection of molding materials with respect to grain size; do not allow stream of metal to strike wall of mold during pouring.

No.	Type of Defect	Cause of Defect	Remedies
11	Weld the seam or fold on casting formed on meeting of two streams of metal with the piled-up edges and oxide film at a joint of a seam (Fig.49, A, B, F, I). A weld is usually superficial, but sometimes penetrates into the interior of the casting.	a) Low metal temperature on pouring.	a) Maintain the established temperature in tapping the metal from the furnace. Use a well heated ladle in good condition for pouring. Avoid incrustation on the tapping spout of the furnace and in the ladle, which strongly absorbs the heat of the metal.
		b) With thin and intricate castings in precision casting the temperature of the mold is important.	b) Do not allow the mold to cool before pouring; the time from the unloading of the molds from the firing oven to their pouring must not exceed 10-12 min.
		c) Incorrect pouring of a fine or discontinuous stream with the pouring cup not full; slow pouring.	c) Maintain full level of the metal in the pouring cup while pour- the molds; enlarge the gating passages. In case of constant de-

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No.	Type of Defect	Cause of Defect	Remedies
			fects of welding, abandon siphon pouring for the part in question.
12	Incomplete pouring, incomplete filling of mold with metal (Fig.49 j).	a) Same as in case of welding.	a) Same as in case of welding (Item 11 a, b and c).
		b) Shortage of metal in ladle.	b) Use measuring ladles; line ladles by sweep; first figure out required quantity of metal and volume of ladle.
		c) Breakout of metal from the mold, due to defects of mold.	c) Same as in mold defect (item 1 a, b, c, and d).
13	Pinchers (shrinkage cavity) - hollow in body of casting.	Incorrect feeding of casting with molten metal. Shrinkage phenomenon.	Same as in defect of shrinkage cavities and internal porosity (see item 1-4).
14	Oxide films.	a) Property possessed by certain alloys with high hot strength very rapid oxidation in molten state.	a) Smelt alloy in reducing, neutral medium, or in vacuum. Use electric arc furnaces or protection by inert gas (for instance argon).
		b) Excessive time for	b) Pour metal as rapidly as

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No.	Type of Defect	Cause of Defect	Remedies
		teeming metal into mold.	possible into mold, in view of the necessary smoothness of the stream. For such pouring, the installation proposed by Academician A.A.Mikulin is recommended.
15	Mechanical damage to casting.	External influences on castings: shock, fracture, etc.	Maintain accuracy in knocking out castings from molds. Extract the castings in the cold state. Use aluminum sledges or hammers with attached rubber disks. Observe safety rules in sandblasting, cut-off, and transportations of parts.
16	Buckling of castings	a) Thermal retardation of shrinkage, explained by the different stresses in the thick and thin parts (tension and compression), during cooling of the casting. b) Shrinkage stresses due	a) Reduce the stresses in the casting by rational design of the casting. Reduce the difference in the wall thickness. Cool all portions of the castings uniformly. b) Increase pliability of

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No.	Type of Defect	Cause of Defect	Remedies
		to resistance of mold	mold. Eliminate projections and closed outlines in the castings, which hinder the free shrinkage of the casting.

Quality Control in Precision Casting

It is generally known that technical inspection consists not only in not forwarding defective parts to further processing and in scrapping castings that do not meet the specifications or foundry drawing, but also in preventing appearance of defects. For this reason, the inspectors of an investment casting shop, in examining the castings on their delivery from the shop (final control) should also monitor the technological process and carry out operational control.

The basic objects of inspection in the precision-casting shop are as follows:

1) Control of raw material;
2) Control of technological process;
3) Control of equipment (dies, measuring instruments);
4) Operational control of all semifinished elements (patterns, assemblies and coated clusters, molds, molten metal);
5) Control of castings;
6) Analysis of internal and external defects.

The check on the raw materials is usually effected by the inspectors of the plant stockroom. Control of the implements is performed at the control and testing stations, or in the central testing laboratory of the inspection department of the plant. Analysis of the internal rejections of the casting shop is performed jointly with the machine shop.

For successful operation of the control service, the technological process of product quality control must be worked out parallel with establishment of the production process. All control operations, with indications of the tolerances and of the necessary control and measuring equipment, must be reflected in the process of manufacturing the part or in the special technological charts.

The control equipment of the shop must be provided with all necessary special and universal control and measuring devices (instruments, gages, calipers, universal measuring tool) and with the technological documentation, which includes: 1) drawing of the part and drawing of the casting (or workpiece), 2) specifications for the casting and for all raw materials to be used; 3) drawings of the instruments; 4) operational process charts and processing instructions; 5) technological control charts.

Rejected castings, depending on the character of the defects are subdivided into:

a) final rejected products - castings that cannot be salvaged or whose salvaging would be economically unadvisable;

b) rejected products that can be salvaged - defective castings where the defects can be corrected by welding or by supplementary machining, making such castings acceptable;

c) conditionally rejected products - castings which deviate from the drawing or specifications, where the character of the defects, however, do not adversely affect the operation of the part when installed in a given equipment. Such castings are not subject to correction, but are released to the production line by arrangement with the designer.

According to the processing point at which the defective castings are discovered, they are subdivided into internal and external: internal, where the defects are discovered in the foundry itself; external, where defects due to the foundry are discovered in the machine shop or in some other shop of the plant. The external defects cause the greatest losses, since, to the cost of the castings themselves is added the cost of their subsequent processing.

Proper organization of inspection in the foundry is one of the most important conditions for lowering the rejection rate of precision casting.

Pattern Inspection. Patterns are checked by external inspection and by instruments. External inspection establishes the soundness of the pattern with respect to the absence of impermissible defects (cavities, clogging, etc.). The dimensional stability of the pattern and the absence of buckling are verified by special calipers, gages and instruments. Divergences in the pattern dimensions are allowed over a range of 0.2-0.3 mm. Possible shrinkage cavities in the patterns are checked by gages viewed against the light. Buckling of the pattern is also detected against the light by means of a feeler gage. The tolerance for this is established in accordance with the subsequent machining of the castings (the existence of machining allowances, the possibility of straightening the castings). In the absence of later trueing of the castings, the tolerance for buckling of the patterns must not exceed 0.3 mm per 100 mm length, since extensive buckling is difficult to correct by machining, in view of the very small tolerances for precision castings.

The process of preparing the pattern mix and the stability of temperature pressure and residence time conditions, in filling the patterns on the press, must be periodically checked. Each assembled pattern cluster is inspected and passed to the production line, if it agrees with the approved standard reference specimen.

Mold Inspection. The quality of the facing layer of the mold must be checked with particular care in the production of precision castings.

Each facing layer is inspected before application of the following layer and before molding; in this case, the layers are checked for absence of cracks, peeling of the coating, and uniformity of the coating.

The raw materials for preparing the facing layer must pass a compulsory test in the plant laboratory. The ethyl silicate is tested for SiO_2 and HCl content; the quartz dust, for SiO_2 content. The process of hydrolysis of the ethyl silicate is entered in a log book. The hydrolyzed ethyl silicate is also tested in the chemical laboratory for its SiO_2 and HCl content.

Periodic check tests must be made on the preparation of hydrolyzed ethyl silicate, presence of the chemical laboratory data on the ethyl silicate and quartz dust batches in production, proper compounding of the coating (checking the specific gravity), coating of the pattern clusters and their processing time in ammonia.

The pattern clusters prepared for molding are subjected to a 100% control after assembly of the molds. The clusters with individual broken patterns and those which do not meet the conditions for producing high-grade molds (existence of specified clearances between pattern and flask, quality of cementing of the cluster to the flask board, etc) are not accepted for molding. Every fifth or tenth batch of molding material must be tested when the ingredients are sprinkled into the mixer. The molding materials (quartz sand and alumina cement) are tested from samples of the batches sent to the sand laboratory of the shop.

From time to time, the vibration time of the molds must be checked, since this has a great influence on the dimensions of the casting and on the strength of the mold.

After natural hardening of the molds and their removal from the flask boards, the integrity of the lower face of the mold must be checked. Molds with breaks on the face, especially near the gate, are not released for subsequent operations.

For certain castings, after melting the pattern mix from the molds, the mold cavity can be examined by a small electric bulb and a mirror; a careful inspection of all such molds prevents the pouring of molds with cracks, collapses, or other defects in the facing layer.

The conditions of drying and firing the molds checked on the tape of the recorder installed on the driers and firing ovens. All fired molds must be inspected before pouring; molds having obvious defects must not be filled with metal.

Work on the mold is the most time-consuming step in the production of precision castings. Preparation of the patterns and clusters, melting of the metal, and pouring of the molds take only minutes, while the making of the molds and their preparation for pouring takes a few days. This makes it all the more important to obtain high-grade molds. The technological control during the entire time of mold-making will greatly increase the quality of the molds.

Control of the Chemical Composition of the Alloys. The composition of the alloy is controlled from the data of the chemical laboratory of the plant or shop. When preparing the alloy from raw materials in the shop, immediately before pouring the molds, 100% of the heats must be tested for the principal alloying element. If verified certificates for the raw materials used in the productive process are available, periodic testing of weighed batches of the charge materials may replace 100% control of the chemical composition of the heats. In that case, a spot check is made of every tenth heat for one or more alloying elements whose contents fluctuates sharply. With such a testing method, each checked tenth heat is considered indicative of the nine preceding heats; from the results of its analysis, the inspection department decides whether all ten heats can be put in production. If the primary and repeated tests show that the content of one or several elements is unsatisfactory, all ten heats must be analysed for these elements, and the production of parts is authorized from the results of the analysis, heat by heat.

In series production, almost no smelting of alloys from the raw materials, followed by immediate pouring of the parts, is done; the method cannot be recommended in view of the small volume of metal smelted and the inevitable difference of the castings in chemical composition of the alloy, which leads to frequent deviations in chemical composition, and to rejection of the casting. If an alloy has to be smelted in the shop, it should be prepared in furnaces of 200-500 kg capacity or more. Each such heat is tested for all elements and is put into production for subsequent remelting and pouring of parts after the chemical laboratory certifies that the alloy is suitable.

In working with tested alloys, either smelted by the shop or delivered by a metallurgical plant, and in using plant scrap, (if reliably stored), it is sufficient to test the chemical composition of the alloy in a single casting every day, for two or three of the most widely fluctuating alloy elements. Such spot testing of the chemical analysis of the alloy has proved adequate over many years of practical work in casting parts by precision casting, at several plants.

Control of the Mechanical Properties of the Alloy. Specimens for the mechanical tests (Fig.50) are taken from the cluster of parts cast. The testing of the mechanical properties on separately cast specimens, as is occasionally done, does not reflect the true condition of the mechanical properties of the casting, since the mold with the specimens is poured under conditions different from those of the parts themselves.

In series production from ready-made alloys, there is no point in testing the mechanical properties of each cluster of castings, and sample tests are also useless since casting of tensile specimens for each cluster is uneconomical. When putting the alloy into production the alloy must be checked for the mechanical properties required for the parts to be cast, by testing several batches of castings using test parts cast together with them; the mechanical properties of subsequent castings are guaranteed by exact observance of the process conditions for the castings.

Control of Castings. The poured clusters of castings after knockout and sandblasting, must be inspected in the untrimmed state (in the clusters). The inspection of castings with the gating system trimmed off does not always give a clear idea on the character of a defect or on the cause for its appearance, in inspecting the untrimmed castings, the origin of many defects becomes obvious. This makes it easier to classify the defects, which means that it also takes less time to figure out a remedy. After inspection in the clusters, the castings are routed to the trimming and cleaning departments, after which they are again subjected to inspec-

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tion.

During the external inspection of the trimmed castings, they are checked for appearance, for conformity with the foundry drawing and for possible correcting of individual defects by additional machining (trimming, welding, straightening). For parts with only insignificant defects, the admissibility of these defects is determined from the specifications (number of cavities, their diameter, depth and location). In external inspection, no complete dimensional check of the castings is made; usually only the length and maximum thickness of the casting as well as buckling (gage along the straight edges) is checked. Castings whose dimensions are within the established tolerances are routed to subsequent operations.

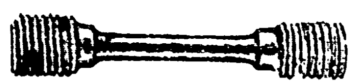

Fig. 50 - Specimen for Testing Mechanical Properties

Castings beyond the limits of the drawing and not meeting the specifications with respect to permissible defects (if they cannot be salvaged) must be rejected, and a rejection slip made out. It is compulsory for this slip to contain the following data: type of defect, and, if due to poor work, the specific person responsible for it. The possibility of correcting the defect is determined by the department foreman and the process engineer. In each individual case, when a casting has a defect and there is any doubt as to the possibility of its correction, the question of passing the part to the subsequent processing is settled by the process engineer of the department, whose decision in the matter is binding both for the foreman and the workers of the inspection department. The situation is the same in determining the cause of the defect. The final decision on the cause of the defect is made by the process engineer. The foreman determines the person responsible for the defect and must show him the rejected part.

Every worker of the shop and the inspection department must understand that forwarding of a defective part to the production line increases the external rejections, makes production more expensive, and increases the danger that the defective part is installed in an equipment. However, before rejecting a part, an effort must be made to salvage it. For improper and premature rejection of a part, those responsible must bear the consequences imposed on deliberate scrappers.

Not all defects of castings, however, can be detected by external inspection; Defects such as internal cavities, porosity, discontinuity of the material, etc. are discovered only by specialized check methods.

For checking the castings for internal defects, fluoroscoping and X-ray examination of castings are used. The former method consists in washing the clean (and sometimes pickled) parts in a highly mobile liquid such as kerosene, and then coating it with magnesia powder or quartz dust. The treated part is then washed off, dried in a stream of compressed air, and irradiated under a quartz lamp. All loose spots of the material, blooming, cracks, brittleness, oxide films, etc., into which the mobile liquid with the powder has penetrated, will luminesce brightly and become distinctly visible. As indicated by the results of the luminescent control, castings with defects exceeding the tolerances are scrapped, while the sound castings are routed to the final inspection, or, in the case of particularly vital castings, to the X-ray examination.

The examination of castings under X-rays reveals all internal defects, including those which do not reach the surface of the casting.

As a rule, X-ray examination in the foundry shops is widely used in the development of the casting process. X-ray examination of all first castings is recommended in order to check on the satisfactory state of the casting material and on the absence of internal defects, especially of porosity. If the X-ray photographs show in defects in the casting, i.e., indicate the satisfactory development of the process, the 100% X-ray examination of the castings is replaced by a spot check on

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20 to 10%.

In some parts it is impossible to obtain an internal structure without porosity. Such parts, as a rule, have design elements unsuitable for casting. In this case, a standard sample of the permissible porosity is established, the spots of allowable defects are specified, and 100% of the castings are examined by X-rays.

Castings that have passed all operational inspections are routed to the final inspection. The final inspection checks the dimensional stability of the castings, as indicated by the foundry drawing; at the same time, the inspection certificates are reviewed and the soundness of the batch of castings is established with respect to chemical composition, mechanical properties of the material, X-ray, and fluorescent examinations.

Finished parts cast by the method of precision casting from alloys having a high hot-strength are usually of a very complex form, so that it is difficult and sometimes ever impossible, to check the dimensions with conventional measuring tools. In series production, special measuring devices must be designed for checking the dimensional stability: calipers, horseshoe gages, other indicating instruments. The use of such devices renders the obligatory 100% checking of the castings for dimensional stability less difficult and greatly accelerates the control procedure.

For dimensional checking of precision castings the following measuring instruments and devices are usually employed: micrometers, caliper gages, surface gages, universal indicator wall gages, curve gages, a set of probes and measuring plates, a control plate, divider head, and a set of prisms.

The dimensions of the castings are verified by special calipers and horseshoe gages in which the inscriptions "Pr" and "Ne" indicate their "go" and "not-go" sides. Those castings in which the "not-go" dimensions (Ne) of the calipers or horseshoe gage pass in the assigned place of the casting, or, on the other hand, the "go" dimensions "Pr", do not pass, are defective castings with respect to this

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dimension and must either be further machined or rejected.

Intricate surfaces are checked by lay-on gages with a stop at a definite point of the cross section. In this case, the maximum allowable clearance between the gage and the casting is prescribed and is checked with a feeler gage.

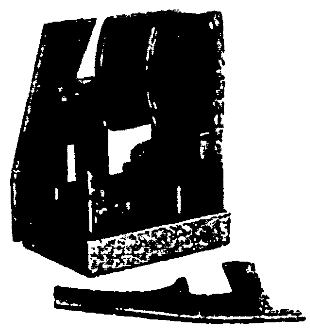

Fig. 51 - Instrument for Measuring Profiles in Two Assigned Cross Sections of a Blade

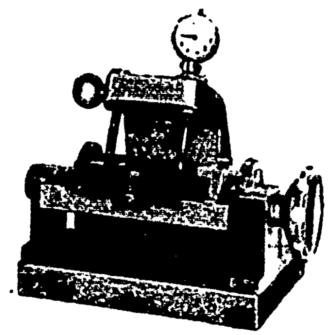

Fig. 52 - Indicator Instrument for Measuring Profiles in Three Assigned Cross Sections of a Blade

Gages are often furnished in sets in special instruments on which the casting is checked along its profile surfaces in the assigned cross section; on such instruments (Fig.51), together with these measurements, sometimes the length, buckling of a casting, deflection of the flanges, etc., is also tested. Figure 52 shows an instrument of more improved design, an indicator dial instrument showing the deflection from the theoretical profile on the casting on each point of the cross section to be tested when a flat copying of the given cross section of the casting connected with the indicator is rolled over it.

Castings found sound by the final inspection are sent to machining and are delivered to the machine shop or the casting store room.

Recording Rejections. Stamping the Castings

Correct recording of the rejections is very important for evaluating the work of a shop for a given time interval with respect to the losses from defective work, with respect to the existence of individual inadequately worked-out operations of the process, and with respect to the observation of the process conditions as a whole. For this reason, most serious attention must be paid to the recording of rejections in precision casting shops and departments.

The recording of rejections is possible only with a correct organization of the productive process, when the castings pass through the productive and control operations in a definite order.

The cast parts are usually processed in batches in the various operations and are accompanied by a document (routing sheet) indicating the number of the batch, date of casting, and number of cast parts. The document enumerates all the productive operations and indicates the number of sound parts accepted for the given operation. At the end of the entire process, the parts arrive at the final control, with a regularly entered number of rejections in each intermediate operation.

After final inspection, the sound parts are delivered to the stock room of the casting shop, and, on the routing sheet, the number of all rejected parts is added up, and the percentage of rejection in the given batch is determined. It must be noted that only by relating the number of rejected parts to the total number of parts cast is a true picture of the spoilage obtained.

The formalization of the rejection for the month must be performed by adding the delivered, rejected, and cast parts from the number of batches delivered in that month. Any other method of calculating the spoilage inevitably introduces errors, since it is very difficult to record the spoilage of parts in the operations themselves, in view of the excessive duration of the productive cycle.

The external rejection is formalized during the course of the month and is added to the internal spoilage. The spoilage of the foundry shop for the month is

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calculated by the following formula

$$P_r = \frac{(B_f + B_m) \cdot 100}{Z}$$

where P_r = percent of rejections in the foundry shop;

B_f = number of rejected parts in foundry shop on all batches delivered during the reporting month;

B_m = number of parts rejected in other shops (due to the fault of the foundry shop) in the reporting month;

Z = number of parts cast in all batches delivered during the report month.

The losses due to rejections are always expressed in rubles and are determined: 1) by the number of rejected castings; 2) by the cost of the metal irrecoverably lost, and the cost of other materials (oxidation losses, unreclaimed losses); 3) the labor used for the castings (total pay); and 4) percent of shop overhead.

It is only natural that the smaller the number of rejected castings and the earlier in the course of the production process the defective casting is withdrawn from the production line, the smaller will be the losses from rejection, and the higher the indexes with which the foundry shop will operate.

Stamping of Castings. The question of stamping castings is of great importance for production. When parts are of the same geometric form, they are differentiated by their assigned number. Sound castings must have the stamp of the control.

The point of stamping is usually prescribed by the drawing of the part. Most often the parts are stamped with the heat number in the foundry, but in investment casting, in view of the relatively numerous heats and the large number of parts, this method of stamping is not always convenient. In addition, a stamp with the heat number alone would be insufficient to distinguish batches simultaneously processed parts, in which there might be metal from several heats.

Parts of minor importance can be stamped with the batch number. In precision casting, the daily production of parts is most often taken as a batch.

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It is more convenient to stamp the parts with the serial number on the unmachined side. This stamping may be performed with an impact stamp immediately after the knockout, but there is a more convenient method of stamping: Before assembly of the clusters, the serial number can be stamped on the pattern at the prescribed locations by means of a sharp steel scriber. With such a method of stamping the part is followed under one definite number until it is mounted in the equipment itself. The serial numbers of the parts may be transferred from the clusters to the mold, entered in the daybooks of drying and firing the molds, and in the melting daybook. They are then entered on the routing sheet. With this method not each sound part has to be stamped by the inspector, just as actual breaking of the rejected parts is no longer necessary. This is all the more important, since only impact stamping is possible on alloys of high hot-strength, since these alloys take acid marking poorly and since marking with paint or an electrograph is destroyed during the subsequent operations of heat treatment and sandblasting of the parts.

Stamping of the parts, beginning with the pattern, requires an insignificant amount of work, but it introduces order into the work and makes it known who has processed the part in each operation, thus completely eliminating the lack of personal responsibility in the production of the parts.

Important parts in precision casting must be stamped only by the above-prescribed method, i.e., by placing a serial number on the pattern and maintaining these serial numbers unchanged during the course of the entire technological process.

XII. DEGREES OF ACCURACY AND FINISH OF DISPOSABLE PATTERN CASTINGS

Dimensional Stability of Casting

It is practically impossible to cast two completely identical castings, just as it is impossible to make two completely identical parts on a metal-cutting machine. One of two parts made by the same method will be slightly larger or smaller than the other in some dimension. For practical work, this difference is of minor importance as long as the part does not exceed the maximum or minimum dimensions at which the given part is suitable for subsequent work, i.e., as long as the part remains within the dimensional tolerances.

Parts can be manufactured with varying degrees of accuracy. As a rule, an increase in the accuracy of production of the parts makes the production more expensive. Thus in machining, the accuracy of manufacture of the machine tool, attachments, and cutting tool, the wear of the cutting tool, the degree of accuracy of the tool setting on the machine, the rigidity of the system machine-tool-part, all exert a direct influence on the degree of accuracy of parts manufacture; other influences are produced by heating of the cutting tool and part, internal stresses of the parts material, and by many other factors.

In casting, the dimensional stability of the part obtained depends on an even larger number of various causes having to do with melting and solidification of the metal, as well as with the use of material of less uniform properties, namely, the mold materials.

The following basic factors affect the accuracy of casting:

1. Accuracy of Patternmaking. The accuracy of the pattern depends mainly on the material of which it is made. A wooden pattern is considerably less accurate than a metal one, since under the effect of air temperature, moisture, and natural wear, a wooden pattern rapidly changes its dimensions. Casting made from wooden patterns are less accurate than castings from metal patterns.

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In precision casting, the low-melting alloys are cast in various dies, which are complicated devices manufactured on metal-cutting machines, with manual adjustment. The dies differ dimensionally. The patterns made from different dies also differ. Pressure-cast patterns are subject to the varying temperatures of the composition poured; in addition, the residence time of the pattern in the die is not always the same, which is true also of the pressure, die temperature, and air temperature. All this leads to the dimensional instability of the patterns and to a decrease in the accuracy of the parts cast from them. The buckling of low-melting patterns under the influence of elevated temperatures and of their own weight exerts a considerable influence on the accuracy of casting.

2. Accuracy of Mold Making. The accuracy of the molds depends on preliminary processing of the raw materials, moisture content of the molding mix, density of the packing, time of packing the mold, drying and firing conditions, fluctuations in the composition of the molding mix, and on many other factors. The duration of the process of mold making for precision casting, with a large amount of manual work, must also be taken into account.

3. Chemical Composition and Temperature of the Molten Metal. The composition of the alloy and the temperature of pouring exert a direct influence on the shrinkage of the metal, on which, in turn, depend the dimensions of the casting. Metal shrinkage is one of the most unstable factors affecting the accuracy of casting. In the disposable pattern method of casting, the metal is teemed into hot molds whose expansion differs, due to the difference of heating during the firing before pouring. The resilience of the mold and the degree of its packing also exert a noticeable influence on the dimensional instability due to metal shrinkage.

4. Cooling of the Poured Forms. The conditions of cooling of the molds after pouring have a considerable influence on the variation in dimension of the part. Rapid cooling of castings often leads to extensive buckling.

The maximum attainable accuracy of processing is significant only in isolated

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cases of tool production or for laboratory studies. For work under industrial conditions, an economically feasible degree of accuracy is fully sufficient. As pointed out by Professor A.I.Kashirin, economic accuracy is defined as the mean deviation of the dimensions of the processed surface from the nominal dimensions obtained under normal productive conditions. As an example, Table 33 gives the data for the mean economic dimensional stability in machining shafts (rough-grinding in this table does not mean rough turning).

Many attempts have been made to classify castings by the dimensional stability after casting. The most successful of these attempts probably is the Standard AN-1026 "Allowances and Tolerances for Nonferrous Alloy Castings", approved in 1951 by the ministry of Aviation Industry.

This Standard covers all forms of casting from nonferrous alloys. Under the subdivision of precision casting, this Standard can also be applied to steel castings. The Standard adopts a symmetrical system of allowances, the value of the allowances being established according to the greatest over-all dimensions of the casting.

The dimensions are designated by types:

D = unmachined linear dimensions of casting;

T = unmachined thickness of casting walls;

H = linear dimensions from unmachined to machined surfaces of casting;

R = dimensions of radii at points of transition of the casting cross sections.

Standard AN-1026 provides for eight accuracy classes for castings, denoted respectively by Lt1-Lt8. The casting accuracy classes must not be confused with the accuracy classes by GOST for machining; their comparison may be made according to the absolute values of the tolerances. Table 34 gives the recommended methods of casting according to the accuracy classes.

The dimensional tolerances of castings in the 1st, 2nd, 3rd, and 8th classes of accuracy are given in Table 35 (the eighth accuracy class is presented for

Table 33

Mean Economic Dimensional Accuracy in Machining Shafts of Length Up to 180 mm

(Minus Deviations from Nominal Diameter, in mm)

According to Data of Professor A.I.Kashirin

b)		a)								c)
		To 10	11–18	19–30	31–50	51–80	81–120	121–180	181–260	
d)	e)	0,18	0,20	0,20	0,30	0,40	0,40	0,40	0,40	5th
	f)	0,09	0,09	0,10	0,15	0,15	0,15	0,20	0,20	4th
g)	h)	0,05	0,06	0,07	0,08	0,09	0,10	0,12	0,12	3a
	i)	0,017	0,019	0,022	0,027	0,030	0,035	0,040	0,015	2nd

a) Interval of Diameters, in mm; b) Form of Machining; c) Accuracy Class by OST (approximate); d) Lathe Grinding; e) Rough; f) Finish with Longitudinal and Transverse Feed; g) Polishing, Round, with Longitudinal and Transverse Feed; h) Preliminary; i) Finish

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comparison). Parts are cast by precision casting, according to the first three classes.

The dimensional fluctuations in precision castings are greatest with respect to length of the castings, especially when there are flanges on the edges of the casting. In this case, the fluctuation in length for a casting of 100-250 mm in dimension amounts to 0.4-0.5 mm and is explained by the hindered shrinkage, due to the pressure of the flanges on the molding mix and the nonuniform resilience of the mold material. The fluctuations in this dimension can be reduced by observing an exact (measured by stopwatch) vibration time of the molds, using the same vibration amplitude of the vibrator.

Table 34

Methods of Casting According to Accuracy Classes by Standard AN-1026

Accuracy Class	Designation of Casting Accuracy Class	Recommended Casting Methods
1	Lt 1	Pressure casting
		Precision casting of parts of medium complexity
2	Lt 2	Pressure casting
		Precision casting of complicated parts
3	Lt 3	Investment casting of particularly complex parts Chill casting of parts of medium complexity
4	Lt 4	Chill casting
5	Lt 5	Casting in chills with sand cores
6 7	Lt 6 Lt 7	Casting in dry and green sand molds with machine molding or pattern boards
8	Lt 8	Casting in dry and green sand molds with manual molding on individual patterns

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Another strongly fluctuating dimension, especially in casting turbine blades, and also for other castings, is the dimension of maximum thickness of the casting profile. This dimension on castings of 120-150 mm length with a maximum profile thickness of 8-10 mm, fluctuates over a range of 0.3-0.4 mm. The fluctuation in maximum thickness is explained by the difficult normal expansion of the mold, by the nonuniform expansion of the material, and by the fact that the material of the mold and flask does not have the same expansion coefficient. The fluctuation in maximum thickness of the casting can be reduced by placing paper or cardboard of 0.2-0.3 mm thickness between the flask walls and the filler; by burning during the firing, this will produce the necessary clearance for expansion of the mold material.

A comparison of the data in Table 33 and Table 35 shows that the accuracy of a casting of the first and second classes (Lt 1 and Lt 2) corresponds to the accuracy of the 3rd and 4th classes OST, which can be obtained by machining, finish-grinding and preliminary polishing, while the accuracy of casting of the third class (Lt 3) correspond to the 5th accuracy class of OST, which is obtained by preliminary grinding on a lathe. The fact that such degrees of accuracy were reached in the foundry industry can be booked as an outstanding success of our advanced Soviet science, which becomes all the more obvious on comparison with the 8th class of accuracy (Lt 8), corresponding to the method of conventional sand casting, which until very recently was the only method used in foundry production.

A further increase in the degree of accuracy in casting of parts with melt-out or burn-out patterns is quite possible. Greater accuracy can be obtained by mechanization of the precision casting process and its automation while maintaining the standardization and constancy of the technological process and materials.

Surface Finish of Precision Castings

Surface finish in machine building is defined as evenness (smoothness) of the surface.

Surface finish plays a very important part in the operation of the parts.

Table 35

Dimensional Tolerances of Casting According to Standard AN-1026

Maximum All-Over Dimension of Casting in mm	Accuracy Classes	Dimensional Deviation in mm					
		D		T		M	
		Upper	Lower	Upper	Lower	Upper	Lower
Up to 25	LT 1	+0,05	-0,05	-0,04	0,04	-0,10	-0,10
	LT 2	+0,08	-0,08	+0,06	-0,06	+0,20	-0,20
	LT 3	+0,20	-0,20	+0,20	-0,20	+0,30	-0,30
	LT 8	+1,10	1,10	+1,30	-1,30	-1,50	1,50
From 25 to 40	LT 1	+0,06	0,06	+0,05	-0,05	+0,10	0,10
	LT 2	+0,10	0,10	+0,08	0,08	+0,20	[illegible]
	LT 3	+0,20	-0,20	+0,20	0,20	0,30	-0,30
	LT 8	-1,40	-1,10	-1,30	1,30	+1,50	-1,50
From 40 to 63	LT 1	+0,08	-0,08	0,06	0,06	0,10	0,10
	LT 2	+0,12	-0,12	+0,10	-0,10	0,20	-0,20
	LT 3	+0,30	0,30	+0,30	-0,30	0,10	-0,40
	LT 8	+1,40	1,40	-1,70	-1,50	1,50	-1,50
From 63 to 100	LT 1	+0,10	0,10	+0,08	0,08	0,20	[illegible]
	LT 2	+0,15	0,15	+0,15	0,15	-0,30	-0,30
	LT 3	+0,30	-0,30	+0,30	0,30	+0,40	-0,40
	LT 8	+1,40	1,10	1,50	1,50	-1,50	1,50
From 100 to 250	LT 1	+0,12	0,12	+0,10	0,10	+0,20	0,20
	LT 2	+0,30	-0,30	-0,20	-0,20	0,40	-0,40
	LT 3	+0,10	-0,10	0,40	0,10	+0,50	-0,50
	LT 8	1,50	1,50	1,70	-1,70	+1,70	-1,70
From 250 to 400	LT 1	+0,15	-0,15	+0,12	0,12	+0,25	-0,25
	LT 2	+0,10	0,10	+0,30	-0,30	+0,50	-0,50
	LT 3	+0,50	-0,50	+0,40	-0,40	+0,70	-0,70
	LT 8	+1,70	-1,70	+1,70	-1,70	+2,00	-2,00

Allowances for Radius

Accuracy Class	Radius					
	To 4,0	From 4,0 to 10	From 10 to 16	From 16 to 25	From 25 to 40	From 40 to 63
LT 1	±0,05	±0,10	±0,15	±0,20	±0,30	—
LT 2	±0,10	±0,20	±0,40	±0,60	±0,80	—
LT 3	±0,20	±0,10	±0,60	±0,80	±1,20	±1,60
LT 8	±1,20	±1,50	±2,00	±2,10	±2,80	±3,50

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Surface finish is decisive for the resistance to wear in combinations of wearing parts, the tightness of fits in compound parts, fatigue strength, and corrosion resistance.

Absolutely smooth surfaces do not exist, even the most carefully machined polished surface will have minute roughnesses in the form of ridges and depressions. To evaluate the profile of a surface and of its finish, various methods are used; the most popular of these is the so-called micro-profiling method, based on the use of instruments that scan the surface with a needle, and record the micro-profile in the form of a profilogram (Abbot profilometer, Levin profilograph, etc.). In the shops, the surface finish is evaluated by comparing it with a standard (the working specimen).

The all-Union standards (GOST 2789-51), define surface finish by the mean height of roughnesses R_{mean} or by the mean square deviation of the roughnesses R_{ms} (the mean-square deviation of the roughnesses of a surface is the square root of the mean-square distance of points of the roughness profile to its center line). The deviation of the roughnesses R_{ms} and the mean height of roughnesses R_{mean} are expressed in microns (μ = 0.001 mm). The standard establishes 14 surface finish classes. Table 36 gives the machining degree, corresponding to surface finishes 1 to 9.

Castings were only recently subdivided into finish classes, since the ordinary methods of casting in sand molds yield a surface finish considerably below the 1st class. The surface finish of a casting, cast into a chill mold, may be placed in the 2nd finish class.

Castings made by the precision casting method have a considerably better surface finish. The most highly finished castings made by this method correspond to R_{ms} = 1.6-1.5 μ. The mean finish of precision castings is R_{ms} = 3.0-1.6 μ. Castings whose finish is considered unsatisfactory in precision casting have a value R_{ms} = 7.0-6.0 μ; such castings are subjected to additional surface finishing.

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Table 36

Surface Finish Classes and Various Corresponding Forms of Machining

Type of Surface	Symbol	Type of Machining	Finish Class: Class Number	Finish Class: Symbol	Finish Class: R_{ms} or R_{mean} in microns
Rough	∇	Roughing Operations of Grinding, Planing, Milling, and Boring	1	∇ 1	Over 125 to 200 (R_{mean})
			2	∇ 2	Over 63 to 125 (R_{mean})
			3	∇ 3	Over 40 to 63 (R_{mean})
Half Finished	∇∇	Finishing Operations of Grinding, Shaving, Boring and Milling	4	∇∇ 4	Over 20 to 40 (R_{mean})
			5	∇∇ 5	Over 3,2 to 6,3 (R_{ms})
		Same Operations, Rough-Polishing, Finish-Drawing	6	∇∇ 6	Over 1,6 to 3,2 (R_{ms})
Finish	∇∇∇	Finish and Diamond Grinding and Shaving, Finish-Boring, Turning and Drawing. Rough-Polishing, Finish-Milling	7	∇∇∇ 7	Over 0,8 to 1,6 (R_{ms})
		Diamond Grinding and Finish-Turning, Finish-Polishing and Drawing	8	∇∇∇ 8	Over 0,4 to 0,8 (R_{ms})
		Diamond Grinding, Shaving and Boring. Finish-Turning. Finish and Fine-Polishing. Finish-Drawing. Finish-Polishing	9	∇∇∇ 9	Over 0,2 to 0,4 (R_{ms})

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Thus the surface finish of precision casting corresponds to the 5-7th GOST classes. The finish may be further improved by using a finer mixture for the facing layer, by increasing its refractoriness, and by reducing the teeming temperature of the metal as much as possible.

Allowances for Machining

The tolerances for machining established in accordance with the maximum over-all dimensions of the casting and the finish class adopted are given in Table 37.

Table 37

Allowances for Machining in Precision Casting

Greatest Over-All Dimensions of Casting, in mm	Allowance Per Side, in mm		
	Accuracy Class		
	Lt 1 - Lt 2	Lt 3 - Lt 5	Lt 6
To 40	0.3	1.0	2.0
From 40 to 100	0.5	1.5	3.0
" 100 " 250	0.7	2.0	4.0
" 250 " 400	1.0	2.0	5.0

The reduction in the allowances for machining, by comparison with other methods of casting, is one of the fundamental advantages of precision casting. The reduction of allowances results in considerable saving of metal and in a reduction of labor and the degree of machining. In the selection of allowances, however, extremes such as very small allowances (under 0.5 mm) should be avoided, since this may lead to rejection of a casting for roughness, despite the fact that the deformation of the parts and skeuring during polishing would be negligibly slight.

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In machining the surfaces of precision castings by polishing, allowances of 0.7-1.5 mm are considered acceptable (for castings with maximum dimensions of 100-250 mm). In hand-polishing of the profiles of turbine blades, in the case of well adjusted dies, the allowances generally are 0.2-0.3 mm per side.

XIII. ORGANIZATION OF PRECISION CASTING

In contrast to all existing casting methods, the process of precision casting is the most time-consuming and technologically complex. This requires even greater care in organizing the productive process, stricter adherence to process conditions, and more accurate control and accounting.

There are two forms of organizing precision casting processes: 1) organization of an independent shop for the production of precision casting; and 2) organization of a department (or section) for precision casting in an operating foundry.

The installation of a special precision casting shop can be justified only where the work volume in the production of precision castings is large, with numerous parts to be produced. In this case it is most advisable to organize the shop according to the so-called object principle, i.e., with a closed cycle of casting and machining and delivery from the shop of parts ready for assembly. Organization of such a shop has many advantages. The principal such advantages include acceleration of the production cycle of parts: reducing the periods between operations and the related increase in the turnover rate of the working capital; close balance of the metal consumed; more rapid and convenient reprocessing of the plant metal waste, including scrapped castings, shavings, and polishing dust (its reclamation must never be neglected); more practical solution of all questions of casting and machining of the part.

In the case of a small number of products and medium-scale production, installation of a precision casting department in an existing foundry is more convenient. This permits the reduction of unnecessary auxiliary services required for the two shops, and, consequently, also a reduction in administrative expense. Every foundry shop has a pattern department, a sand, an X-ray, and rapid-check laboratory, to say nothing of the sand stockpiles and other services which are also in a position to serve the production of precision castings. The existence of a precision-casting department within the foundry shop greatly extends the possibilities of the casting shop in the production of small castings in dry cores, whose casting does not interfere with the production of precision castings. At the same time, a large and well-organized foundry shop is in a position to introduce and efficiently organize the production of precision castings.

In each individual case, the problem of organizing the shop or section of precision casting is solved in accordance with the group of circumstances as a whole. The question of space is also of great importance, the availability of space often being the determining factor for installation of a precision casting shop or section as a part of a foundry shop.

All problems of organizing the production of precision castings considered here refer to a precision casting section, but are also applicable to a precision casting shop.

The Shop Layout and Organization Chart

Figure 53 gives the layout for a precision casting shop designed to produce one million castings (250 tons) a year.

This shop is designed for organizing the production on the production-line system. Such a system facilitates acceleration and, at the same time, constancy of the process conditions and careful observance of the adopted process chart.

For small-scale production, other organizational forms for precision casting of parts may exist. In many plants, the manufacturing of parts is done in batches. However, such processing leads to considerable time intervals between the operations and interferes with standardization of the product. Even in small-scale production, every effort should be made the production-line system, thus reducing the inter-operational delays and permitting the treatment of parts under identical

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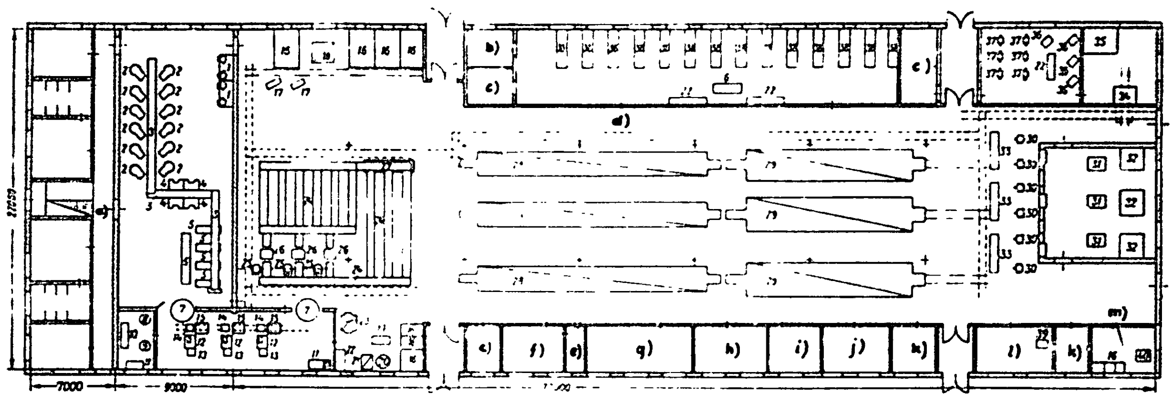

Fig.53 – Plan for Shop for Producing 1 Million Precision

Castings a Year (250 tons)

1 - Electric bath for preparing pattern mix, 2 - Pneumatic press, 3 - Conveyor, 4 - Bench for cleaning patterns, 5 - Drawers for assembling patterns, 6 - Inspection desk, 7 - Rotating conveyor racks, 8 - Hydrolyzer, 9 - Tank for raw ethyl silicate, 10 - Chest of drawers, 11 - Laboratory table, 12 - Coating bench, 13 - Sand slinger; 14 - Conveyor rack, 15 - Ammonia cabinet, 16 - Bin for free-flowing materials, 17 - Mechanical screens, 18 - Oven for drying sand, 19 - Vibrating machine for sifting quartz dust, 20 - Tank for washing quartz dust, 21 - Electric drier for drying quartz dust, 22 - Rack, 23 - PN-13 oven for firing quartz dust, 24 - Roller conveyor for drying molds; 25 - Mixers, 26 - Vibrators, 27 - Installation for melting pattern material, 28 - Drier for drying molds; 29 - Oven for firing molds, 30 - High-frequency smelting furnaces, 31 - Generators, 32 - Capacitor batteries, 33 - Pouring tables, 34 - Elevator for lifting molds to knockout, 35 - Sandblasts, 36 - AMO-32 machine, 37 - Emery grinding wheels, 38 - Fitter's benches, 39 - Decimal scales, 40 - Hammer crusher.

a) Sanitary facilities, b) Tool stockroom, c) Stockroom for finished parts, d) Rail line, e) Warehouse for rejects; f) Office for shop inspection, g) X-ray laboratory, h) Fluoroscoping department, i) Sand laboratory; j) Rapid-check laboratory, k) Stockroom, l) Charge yard, m) Room for lining work.

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conditions.

The number of workmen employed in a precision casting section depends on the productive program for the manufacture of precision castings. If four castings are being produced in a mechanised production-line department, with an output of one million castings per year (6000 sets), the number of workmen and engineering personnel might roughly correspond to that given in Table 38.

Technical Documentation

Proper formulation of technical documentation and the quality of the technical documents is very important in process organization.

The production of parts, including that of castings, begins with making a blueprint of the part. The drawing of the part, arriving at the shop is worked up by the process engineer from the viewpoint of casting technology. In the foundry shop, a foundry drawing of the part is issued and is approved by the machine shop; when design modifications must be made in the part, approval by the designer is required. The acceptance of castings in the foundry shop and their delivery to the stockroom is performed in accordance with the foundry drawing. Another basic technological document, which is a law for the production, is the list of technological processing charts kept by the process engineer, in charge of the parts manufacture. The technological processing charts must be brought up to date for all vital operations of the process to which the casting is subjected along the line. The process instructions must not be of a descriptive and meandering character, but must give concise and brief instructions as required for performing a given operation. The instructions must indicate all conditions of work, as well as all transitions and working stages of the given operation. The process chart must contain the following entries: inspection requirements of the given operation; method of inspection; testing instruments and allowable defects, etc. Attachment of the necessary sketches with indications of the dimensions is of great help in the work.

Table 38

Approximate Schedule for Workmen and Engineering

Personnel of a Precision Casting Department

Trade and Duty	Category or Pay-Group	Number	Remarks
I. Productive Workers			
Compounders of pattern material	4-5	4	
Pattern stampers	4-5	24	
Pattern finishers	4-5	8	
Cluster assemblers	5-6	8	
Coaters	5-6	6	
Sand operators	3-4	6	
Molders	4-6	12	
Driers	4-5	4	
Mold assemblers	4	2	
Metal teemers	5-6	6	
Steel founders and smelters	5-7	9	
Knockout men	4-5	6	
Sandblasters	4-5	4	
Trimmers	4-5	8	
Fitters	4-6	30	
	Total	137	
II. Assistants			
Laboratory and apparatus workers	6-7	4	Not counting laboratory workers in plant laboratories

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Trade and Duty	Category or Pay-Group	Number	Remarks
Fitters-adjusters on the conveyor	6	2	Not counting fitters on repair in mechanical group and in pattern department
Machinists for electric generators	6	3	
Pyrometer men	5–6	4	
Shift electric repairmen	5–6	4	
Inspectors	4–6	15	
Distributors	4–6	4	
Transport workers	3–4	4	
	Total	40	
	III. Engineering Personnel		
Chief of department, also assistant chief of precision casting shop	On General Plant Payroll	1	
Senior foremen of section		3	
Shift foremen		7	
Foremen for preparation of production		1	
Senior process engineer		1	Administratively subordinated to chief of technical bureau of shop
Process engineers		3	
Senior inspection foremen		1	Administratively subordinated to chief of bureau of shop control
Inspection foremen		1	
Planner		1	
	Total	19	

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Trade and Duty	Category or Pay-Group	Number	Remarks
IV. Junior Service Personnel			
Cleaners		4	
		Total 200 Men	

The process charts are drawn up by the process engineer, in collaboration with the foremen, and are approved by the chief of the shop and by the chief metallurgist of the plant. No one has a right to modify any entry in the process conditions. All modifications are entered (with a special prescription and reference) by the process engineer handling the part in question after approval of the modification sheet by the chief metallurgist.

The file of the technological operation charts (original) is kept in the department of the chief metallurgist; one copy each of the blueprints in the technological bureau of the shop and in the office of the shop inspection; and one working copy of the blueprints in the section. It is common practice to paste this copy on plywood, coat it with colorless varnish, and hang it at the working position so that the process conditions are always before the eyes of the workmen performing the operation in question.

At times, it is impossible to describe certain processes in the process specification. Special instructions are prepared for such processes, with the process operations chart refering to such instructions. These include, for example, instruction on the hydrolysis of ethyl silicate, lining of furnaces, etc. The instructions, if reference is made to them in the process conditions, have the validity of a process operation chart, and one copy must be available to the operators of this process step.

The flow sheet, or over-all schedule, is a particularily important document.

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This document reflects all changes in a batch of parts during its movement through the operations. The flow sheet enumerates all operations to which the parts are subjected up to their delivery to the casting stockroom. Usually the flow sheet is initiated at the smelting step but may also begin with the step of cluster assembly. In it are entered the heat number, the number of the part or article, the date of casting, the number of parts cast, and their serial numbers. The passage of parts through the operations is fixed by operational control, which notes on the flow sheet the number of sound and rejected parts. The name of the workman performing each operation is entered for each operation. The end of the flow sheet contains a blank Table, giving the reason for scrapping a casting and a list of all rejected parts, in the corresponding column; at the end, the number of castings delivered and the invoice numbers under which they have been delivered are given.

The routing sheet is a very convenient document for keeping a record of the parts on the production line. It is also convenient to give a record of the spoilage. For this, at the end of a month, it is only necessary to add up the number of cast and spoiled parts, arranged by batches delivered during the reporting month.

To avoid confusion of the parts in the individual process steps and to prevent losses, the processing of the parts should be done in batches, each such batch being accompanied by the above-described routing slip.

With a properly adjusted production line, no parts can be lost. The person guilty of losing a part must bear the same responsibility as for a rejection. Those responsible for the safekeeping of parts are the foremen of the section where the part is being treated and the workman processing a given batch of parts. The parts are delivered from section to section against a receipt record, which is made easier to keep by using a standard container with compartments for transportation of parts. A record of the parts as a whole, for the precision casting department, is kept by the planner, to whom all reports are submitted by the foreman on production of parts and movement of batches of parts.

Delivery of finished castings to the stockroom is done by invoice.

Test specimens for chemical analysis are sent to the laboratory under the number of the routing sheet of the batch of parts to be controlled, and the laboratory certificates are returned to the inspection department under the same numbers, which prevents possible confusion. The requests for tests are made out on a special blank.

Each sheet is registered in the heat book, with a statement of the number of molds poured and their numbers. It is more convenient to keep the smelting records separately by alloys.

The productive and control devices (dies and instruments) must have special rating certificates, which are kept together with the devices in the tool stockrooms or in the section. After checking the devices in the control and verification station or in the central testing laboratory, the results of the check are noted in the rating certificate. The same is done with respect to correction of such devices. All corrections made are noted in the rating sheet of the device. Attachments and instruments are checked by a strictly laid-out graph.

The rejection of castings is formalized by drawing up special rejection charts.

All other documentation, such as workmen's pay schedules, blanks for tabular records, etc., will not be discussed here, since they are the same for every production line.

Safety Regulations

Special safety regulations are issued for all enterprises doing precision casting. A number of agencies have summarized these instructions, which are now being issued as mandatory.

In the following, only particularly important questions of plant safety in precision casting will be considered.

In selecting a pattern material, no toxic substances, such as holowax, must be used. A pattern mix with polystyrene is a combustible material. If it is used,

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all rules of fire safety must be observed. As far as possible, the use of an open flame must be forbidden in the pattern department, and in no case must the equipment for heating the pattern material be left unsupervised.

In the departments where patterns are made and coated, particular attention must be given to proper functioning and efficiency of the ventilation. The ventilating devices, when working with molten pattern material, must be periodically cleaned to remove any pattern material condensed in the pipes.

The molten material for patternmaking may cause injury. Precautionary measures must be taken in melting and pouring such material, and special screens must be used, especially on the pattern presses, where hot pattern material may spatter under the action of the pressure exerted by the press. For pattern coating rubber gloves must be worn and the work must be done under a hood, since the ethyl silicate or liquid coating may splash. Sanding of the coated patterns and the ammonia treatment of the pattern clusters must also be performed under a hood, with the equipment in good condition.

There are a number of dangerous operations in preparing the materials, coating the pattern clusters with a facing layer, and molding. These operations include:

1) Firing the sand and marshallite, which must be done with great caution, charging and discharging the electric oven only when it is turned off; do not allow fired sand to spill on the floor and to cool there;

2) Screening of sand, cement, and especially of quartz dust; the sifting of these materials must be done under a hood;

3) Transportation of heavy molded flasks, for which a roller conveyor must be used; in molding on the vibrator, care must be taken to avoid possible splashing of the molding material.

The melt-out of the pattern material from the molds with the temperature rising above the allowable limit is often accompanied by ignition of the material. Dewaxing of the molds must therefore be performed at the established temperature,

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and no excessive rise must be permitted.

The molds must be charged into the electric furnaces and removed with the electric heaters turned off; a blocking device which disconnects the current in the furnace when the door is opened must be installed at the furnace doors. The hot fired molds may crumble, or in the case of flaskless molding, may collapse, if carelessly transported. The fired molds must be transported with extreme caution, using special tongs, adjusted to the size of the molds.

The melting of metal and the teeming of metal into the molds is a particularly dangerous step of the process. The pouring of molds is done on special machines, with the molds placed on a bed of dry sand.

Persons not having attended a special course of instruction are forbidden to work on the high-frequency installation.

The generator room must be isolated and must have a reliably working blocking door which, on opening, disconnects the installation. All current-carrying parts of the machines and furnaces, as well as the busbars must be well screened. The smelting of metal is to be done only in furnaces in good order with a reliable lining. When the lining is corroded, the molten metal must be immediately tapped into a ladle or receiver. In smelting of metal, a tool with insulated handles is used. Do not allow charging of a damp charge into the molten metal and prevent penetration of moisture. The metal must be teemed only into ladles in good condition. The smelters and pourers must wear special protective clothing (heavy cotton overalls, gloves, felt boots; trousers are worn inside the boots) and must use protective goggles with blue lenses.

Hot molds must never be knocked out.

Only properly trained personnel who has passed a medical examination, is allowed to work on the sandblasting machine. In sandblasting work, protective suits with a helmet must be used (in case of an open sandblast), and rubber gloves must be worn. The sandblast room must be protected by wet filters and high-power

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ventilation systems.

Work with an abrasive tool or polishing wheels is permitted only when properly installed, with the necessary fiber gaskets and disks. Polishing wheels must pass a preliminary test and be properly transported. Trimming machines, emery wheels, and polishing heads must be provided with reliable safety screens.

Every new employee must take a compulsory six-shift course of instruction on safe methods of work for the operations assigned to him, with successful completion of the course entered in a record book. Every six months, this course is repeated for all workmen. All personnel working in the shop must be familiar with the general rules of safety and fire protection.

The productive rooms of the shop, the equipment, the recreation and sanitary facilities of the shop must meet all safety requirements and all labor protection rules.

The fire-protection measures in the shop must meet the requirements for fire protection issued by the Ministry of Internal Affairs USSR.

Measures for Increasing Labor Productivity

In increasing the productivity of precision casting, the decisive factors are the materials used, arrangement of the largest possible number of castings in a single cluster, improvement of the quality of the castings, and reduction of spoilage.

A large number of examples could be cited where productivity has been increased as a result of the tireless work of rationalization performed by innovators of socialist production. In one of the departments of the precision casting shops, patternmaker P.V.Kudishina proposed a method of simultaneous work on two dies in patternmaking. This measure increased labor productivity in the pattern department by almost 70%.

The introduction of ammonia treatment of the coated pattern clusters shortened the coating cycle from 30-40 hrs to 2-3 hrs.

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The rational utilization of the working space of a firing furnace, by charging stacked molds, almost doubled the productivity of the mold-firing equipment.

Simultaneous molding on a large-capacity vibrator of several molds, as proposed by the molders Comrades Soldatova and Kus'mina (at one and the same time in different plants), has much increased the productivity of this operation.

Comrade Gunkina, a pattern cluster assembler, proposed cooling the jig with water during assembly of the patterns, which shortened the assembly time.

In working on a rotary furnace, the founder Comrade Nefterev abandoned the use of unnecessary clamps for attaching the graphite cover, thus shortening the auxiliary labor time in the smelting process.

Possibilities for further increase in the productivity of precision casting may lie in a maximum mechanization of the production operations, automation of equipment, and use of more suitable materials.

A more refractory pattern material will further improve the pattern quality, eliminate their buckling and excessive shrinkage, which will necessarily be reflected in an increase of productivity in the operation of patternmaking, since it allows a shorter pressing time and residence time in the dies.

Dry fillers should find widespread use in precision casting, since its use greatly shortens the duration of the productive cycle in the drying and firing of the molds. Precision casting engineers must search for a satisfactory molding material that does not impair the dimensional stability of the castings.

A persistent day-to-day fight against spoilage has already borne fruit in many enterprises. The output of sound castings has been increased; and for a number of parts cast by the method of precision casting, the rejection rate has been reduced to tenths of a percent. But there is still a large amount of work to be done in the field of reducing spoilage and scrap.

If the present book makes it easier for the workers in precision casting to fight spoilage, even if to a minor degree, and if it helps the cause of training young workmen in precision casting, the author will consider his task well done.

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